ECONOMIC GEOLOGY

EDITOR

ALAN MARA BATEMAN

Yale University, New Haven, Connecticut

BUSINESS EDITOR

WILLIAM SHIRLEY BAYLEY

University of Illinois, Urbana, Illinois

ASSOCIATE EDITORS

WALDEMAR LINDGREN
Mass. Institute of Technology, Cambridge, Mass.

G. F. LOUGHLIN
U. S. Geological Survey, Washington, D. C.

C. N. FENNER
Geophysical Laboratory, Washington, D. C.

B. S. BUTLER
Univ. of Arizona, Tucson, Ariz.

W. E. WRATHER
Dallas, Texas

HEINRICH RIES
Cornell University, Ithaca, N. Y.

I. M. GOUBKIN
Moscow, U. S. S. R.

PAUL RAMDOHR
Univ. of Berlin, Germany

CHARLES KENNETH LEITH
University of Wisconsin, Madison, Wis.

E. C. ANDREWS
Sydney, Australia

E. L. DEGOLYER
New York, N. Y.

E. S. MOORE
University of Toronto, Toronto, Can.

PER GEIJER
Royal Technical University, Stockholm, Sweden

TAKEO KATO
Imperial University, Tokyo, Japan

ALEX. L. DU TOIT
Johannesburg, South Africa

J. A. DUNN
Geological Survey, Calcutta, India

VOLUME XXXIV

NEW HAVEN, CONNECTICUT.

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

1939

SOCIETY OF ECONOMIC GEOLOGISTS

THE PUBLICATIONS OF WHICH CONSTITUTE
A PART OF THIS JOURNAL

OFFICERS FOR 1939

E. S. MOORE.....*President*
W. D. JOHNSTON, JR.....*Secretary*
G. F. LOUGHLIN.....*Pres. Elect*
G. D. LOUDERBACK....*Vice-President*
J. T. SINGEWALD, JR.....*Treasurer*
J. B. TYRRELL.....*Vice-Pres. Elect*

Councilors

1939	*1940*	*1941*
G. H. ASHLEY	O. E. MEINZER	JAMES GILLULY
C. H. BEHRE, JR.	F. H. LAHEE	W. J. MEAD
A. W. PINGER	I. B. JORALEMON	T. B. NOLAN

Regional Vice-Presidents

PAUL RAMDOHR.....Berlin, Germany.....*For Europe*
J. A. DUNN.....Calcutta, India.....*For Asia*
N. R. JUNNER.....Prestea, Gold Coast Colony, Africa.*For Africa*
VICTOR DOLMAGE.....Vancouver, Canada.....*For North America*
F. R. KOEBERLIN.....Santiago, Chile.....*For South America*
H. C. RICHARDS.....Brisbane, Australia.....*For Australia*

Executive Committee

E. S. MOORE, *Chairman* — ALAN M. BATEMAN, *Vice-Chairman*
D. H. MCLAUGHLIN — PHILIP KRIEGER — L. C. SNIDER

Finance Committee

JAMES T. DUCE, *Chairman* — ARTHUR NOTMAN
S. H. BALL — W. J. MEAD

Program Committee

C. H. BEHRE, JR., *Chairman* — Q. D. SINGEWALD
C. D. HULIN — H. E. MCKINSTRY

Committee on Publications

B. S. BUTLER, *Chairman* — E. L. DEGOLYER — W. C. MENDENHALL

CONTENTS OF VOLUME XXXIV

Number 1.

The Nickel-Cobalt-Native Ore Type.....*Edson S. Bastin* 1
Diaschistic Dikes and Ore Deposits.....*J. E. Spurr* 41
The Pyrosynthesis, Microscope Study and Iridescent Filming of Sulphide Compounds of Copper with Arsenic, Antimony and Bismuth
A. M. Gaudin and Günther Dicke 49
The Lead-Zinc Ore Deposits and Geology of The Arbus in Sardinia, Italy.....*Charles Will Wright* 82
Geology of the Bonanza King Mine, Humboldt Range, Pershing County, Nevada.....*Donald F. Campbell* 96

Discussion and Communications:
Sedimentary Deposits of Copper, Vanadium-Uranium and Silver in Southwestern U. S.....*H. A. Raggatt* 113

Reviews:
Gold Deposits of the World (Emmons).....*L. C. Graton* 116
The Properties of Glass (Morey).....*W. S. Bayley* 120
About Petroleum (Crowther).....*W. S. Bayley* 121
Outline of Historical Geology (Wells).....*W. S. Bayley* 121
Metalliferous Deposits of the Cascade Range, Oregon (Callaghan and Buddington) 122
Lexicon of Geologic Names of the United States (Wilmarth)..... 122
Books Received.....*J. D. Bateman* 122

Society of Economic Geologists:
Abstracts of Papers to be Presented at Annual Meeting..... 125

Scientific Notes and News..... 140

Number 2.

Metasomatic Origin of the Adirondack Magnetite Deposits
Harold L. Alling 141
Ore Geology of the Day Dawn Mine, New Guinea.....*N. H. Fisher* 173
Origin of the Sweetwater, Tennessee, Barite Deposits..*Robert A. Laurence* 190
Ruby Gulch Gold Mining District, Little Rocky Mountains, Montana
J. L. Dyson 201
The Pyrosynthesis, Microscope Study and Iridescent Filming of Sulphide Compounds of Copper with Arsenic, Antimony and Bismuth. Part II
A. M. Gaudin and Günther Dicke 214

LINDA HALL LIBRARY
KANSAS CITY, MO.

Discussion and Communications:
Seventh Assembly, International Union of Geodesy and Geophysics
D. H. McLaughlin 233

Reviews:
Thetford, Disraeli and eastern half of Warwick Map-Areas, Quebec (Cooke and Clark) ..... *George W. Bain* 235
Lexicon de Stratigraphie. Vol. I, Africa (Haughton) ... *W. S. Bayley* 237
Manganese (Groves) 238
Micropedology (Kubiëna) ..... *W. S. Bayley* 238
Mineral Valuations of the Future (Leith) 239
Geology and Mineral Resources of the Honeybrook and Phoenixville Quadrangles, Penn. (Bascom and Stose) 239
Books Received ..... *J. D. Bateman* 239

Scientific Notes and News 242

Number 3.

A Preliminary Account of the Geology of a Portion of the Lupa Goldfield ..... *David Gallagher* 243
The Iron Ores of the Wichita Mountains, Oklahoma ..... *C. A. Merritt* 268
Mineral Resources of the Chemical Industries
R. N. Keller and T. T. Quirke 287
Geologic Parallels: Hog Mountain, Alabama, and Paracale, Philippine Islands ..... *Edward Wisser* 297
Sienna ("Ocher") Deposits of the Cartersville District, Georgia
Thomas L. Kesler 324

Discussion and Communications:
Magnetite Crystals from Meteoric Solutions ..... *John W. Gruner* 342
Dislocated Inclusions in Gold-Quartz Veins at Grass Valley, California ..... *W. A. Wiebenga* 343

Reviews:
Geology of the "Questa" Molybdenite Deposit, Taos County, New Mexico (Vanderwilt); Childs-Adwinkle Mine, Copper Creek, Arizona (Kuhn); The Mammoth Mining Camp Area, Pinal County, Arizona (Peterson) ..... *B. S. Butler* 347
Geological Map of California (Jenkins) ..... *W. S. Bayley* 351
Architecture of the Earth (Daly) ..... *Alan Bateman* 351
Quartz Family Minerals (Dake, Fleener and Wilson) 352
The Examination of Fragmental Rocks. Rev. Ed. (Tickell)
W. S. Bayley 352
Regionale Geologie der Erde. Vol. I, Pt. VI, The Indian Peninsula and Ceylon (Cotter); Pt. VII, Middle and West Australia (Clarke) 353
Books Received ..... *J. D. Bateman* 353

Society of Economic Geologists:
Program of California Meeting, August 8–10, 1939 355

Scientific Notes and News 356

Number 4.

Structural Relations of Some Gold Deposits Between Lake Nipigon and Long Lake, Ontario ..... *E. L. Bruce* 357
Coal Metamorphism in the Anthracite-Crested Butte Quadrangles, Colorado ..... *E. C. Dapples* 369
Significance of Bornite-Chalcocite Microtextures ..... *G. M. Schwartz* 399
Shades and Screens for Isometric Block Diagrams ..... *Ronald L. Ives* 419
Telluride-Tungsten Mineralization of the Magnolia Mining District, Colorado ..... *Albert S. Wilkerson* 437
Slates of East Tennessee ..... *H. C. Amick* 451

Discussion and Communications:
Texas Surface Soils ..... *William F. Tanner* 459
"The Gold Missus" (Fowler-Lunn) ..... *T. Hirst* 460

Reviews:
Mine Examination and Valuation (Baxter and Parks) ..... *T. S. Lovering* 462
Practical Seismology and Seismic Prospecting (Leet) ..... *Alan Bateman* 463
Die Bergwirtschaft der Erde. Bodenschätze, Bergbau und Mineralienversorgung der Einzelnen Länder (Friedensburg) ..... *W. S. Baley* 464
Annotated Bibliography of Economic Geology, General Index, Vols. I–X, 1928–1938 464
Spot Tests (Feigl) Tr. Matthews 464
Books Received ..... *J. D. Bateman* 465

Society of Economic Geologists:
Abstracts of Papers to be Presented at California Summer Meeting 467

Scientific Notes and News 473

Number 5.

Nomenclature of the Megascopic Description of Illinois Coals ..... *Gilbert H. Cady* 475
The Geology of the Canadian Malartic Gold Mine, N. Quebec ..... *D. R. Derry* 495
The Relationship of Structure to Petroleum Production in Eastern Venezuela ..... *Willard Miller* 524
Action of Alkali Sulphide Solutions on Minerals at Elevated Temperatures ..... *J. L. Lindner and John W. Gruner* 537
Measurements in Block Diagrams ..... *Ronald L. Ives* 561
The Oolitic Limestone Deposits of Franklin County, Alabama ..... *Walter B. Jones* 573

Discussion and Communications:
Magnetic Surveys in Michigan Copper Country ..... *T. M. Broderick* 581

Reviews:

Geology, Principles and Processes, 2nd edit. (Emmons, Thiel, etc.) *C. H. Behre, Jr.* 582

The Birth and Development of the Geological Sciences (Adams) *Alan Bateman* 584

Miocene Stratigraphy of California (Kleinpell) 584

Geologische Jahresberichte, Bd. 1 (ed. Bubnoff) ..... *W. S. Bayley* 584

Books Received ..... *J. D. Bateman* 585

Scientific Notes and News 588

Number 6.

Geological Factors in the Valuation of Mines ..... *Donald H. McLaughlin* 589

Some Geological Features of Kolar, Porcupine and Kirkland Lake *E. Y. Dougherty* 622

Outcrops of Ore Shoots ..... *Harrison Schmitt* 654

The Primary Mineralization at Chuquicamata, Chile, S. A. *Victor M. López* 674

The Montauban Mineralized Zone, Quebec ..... *F. Fitz Osborne* 712

Discussion and Communications:

Dislocated Inclusions in Veins ..... *C. B. E. Douglas* 727

Reviews:

Geology and Ore Deposits of the Lordsburg Mining District, New Mexico (Lasky) ..... *Philip Krieger* 731

The Nature and Origin of Coal and Coal Seams (Raistrick and Marshall) ..... *Gilbert H. Cady* 732

Our National Resources and Their Conservation (Parkins and Whitaker) 734

Descriptive List of New Minerals, 1892–1938 (English) 734

A Textbook of Geomorphology (Worcester) 734

Books Received ..... *J. D. Bateman* 735

Scientific Notes and News 737

Number 7.

A Silver-Pitchblende Deposit at Contact Lake, Great Bear Lake Area, Canada ..... *G. M. Furnival* 739

Metasomatism of Country Near Ore-Bodies and its Possible Economic Significance ..... *E. deC. Clarke and H. A. Ellis* 777

Manganese Mineralization at Tombstone, Arizona .... *Charles Alfred Rasor* 790

Notes on the Uses of Methyl Methacrylate "Lucite" in a Geological Laboratory ..... *James Forbes Bell* 804

Asbestos and Chromite Deposits of Wyoming ..... *R. H. Beckwith* 712

Discussion and Communications:

Alterations of Ilmenite ..... *J. G. Koenigsberger* 844

Reviews:

Geology and Allied Sciences. Thesaurus and Coordination of English and German Specific and General Terms (Huebner)..*W. S. Bayley* 845
Strategic Mineral Supplies (Roush).....*Alan Bateman* 845
Geomorphology. An Introduction to the Study of Landscapes (Lobeck).....*Alan Bateman* 846
A Source Book in Geology (Mather and Mason)..... 847
Internal Constitution of the Earth. Physics of the Earth VII (Gutenberg ed.)..... 847
Books Received.....*David Gallagher* 847

Scientific Notes and News..... 850

Number 8.

Waldemar Lindgren.....*L. C. Graton* 850a
The Geology and Development of Mill Close Mine, Derbyshire..*J. G. Traill* 851
Metasomatism Associated with Tertiary Mineralization in New Guinea
N. H. Fisher 890
Manganese in a Thermal Spring in West-Central Utah
Eugene Callaghan and H. E. Thomas 905
Magnetite and Hematite Veins in Triassic Lavas of Nova Scotia
A. P. Hornor, Jr. 921

Discussion and Communications:

Alteration of Ilmenite.....*E. S. Moore* 931

Reviews:

Market for Columbia River Hydroelectric Power Using Northwest Minerals (Hodge).....*Vernon E. Scheid* 932
Annual Reviews of Petroleum Technology (Garner, ed.)..*W. S. Bayley* 933
Minerals Yearbook, 1939 (Hughes, ed.)..... 933
Terrestrial Magnetism and Electricity. Physics of the Earth VIII (Fleming, ed.)..... 934
Earthquakes and Other Earth Movements (Milne)..... 934
Books Received.....*David Gallagher* 935

Society of Economic Geologists:

Announcements..... 938
Abstracts of Papers to be Presented at Minneapolis Meeting..... 939

Scientific Notes and News..... 949
Index, Volume XXXIV..... 950
Contents, Volume XXXIV..... iii

SCIENTIFIC NOTES AND NEWS

H. A. BUEHLER was recently honored at a testimonial dinner given by the citizens of Rolla, Missouri, to celebrate his 30 years as State Geologist.

EDWARD SAMPSON, professor of economic geology, Princeton University, was married on October 20 at Albany, New York, to Katherine Westerlo Van Rensselaer, daughter of Mrs. Benjamin Walsworth Arnold.

J. C. HAFF, petrologist, has been appointed assistant professor of geology for the ensuing year at the Colorado School of Mines. He received his Ph.D. from Columbia and studied petrologic methods at Innsbruck and Zurich.

J. K. GUSTAFSON whose office address is Royal Bank Building, Toronto, is now with Hollinger Consolidated Gold Mines, Ltd.

ARMOUR INSTITUTE OF TECHNOLOGY and the LEWIS INSTITUTE, both of Chicago, are amalgamating to form the ILLINOIS INSTITUTE OF TECHNOLOGY. Actual consolidation of the educational program will be complete by September, 1940.

G. W. TOWER, JR., geologist and mining engineer with Guggenheim Brothers until 1937, died September 13 in Denver, Colorado.

The INDUSTRIAL MINERALS DIVISION of the A. I. M. E. held a Fall meeting in cooperation with the INSTITUTE OF CERAMIC ENGINEERS at Tuscaloosa, Ala., Nov. 2–4. Some 16 papers were offered, and five excursions held. Papers of particular geologic interest were: Limestones and Dolomites of Ala., S. I. Lloyd; Kyanite in the Piedmont, E. Bowles; Alabama Marble, W. H. Runge; a Discovery of Bentonite in Ala., E. Bowles; Georgia Ocher in Portland Cement, G. W. Jordan; Kaolin and Mica Fines, J. A. Barr; Bentonite, P. Bechtner; Ball Clay in W. Tenn., R. B. Carothers; Spodumene in N. Carolina, T. L. Kesler; Phosphate Rock Reserve in Tenn., G. I. Whitlach; Barite, Fluorite, Galena, Sphalerite Veins in Middle Tenn., W. B. Jewell.

The CAROLINA GEOLOGICAL SOCIETY held its 4th annual meeting at Spruce Pine Oct. 21–22. Visits were arranged by B. C. Burgess to McKinney, Pitman and Whitehall feldspar mines; Newdale Olivine Mine; Spruce Pine Mica Plant; Kaolin, Inc.; Gunter Chlorite Mine; Victor Mica Co.; Mica schist plant; Minpro feldspar plant; Sparks Clay mine; Harris Clay Co. new mine; Gerhardt Mine of the N. C. Pyrophyllite Co.; and the Celo Mines, for 25 members and 45 guests.

Newly elected officers are: Pres., J. H. Watkins; Vice-Pres., W. J. Alexander; Sec.-Treas., Willard Berry, Duke University, Durham, N. C.

THE GEOLOGICAL SOCIETY OF LONDON announces that the 18th session, International Geological Congress set for July 31–Aug. 8, 1940, in London, is postponed indefinitely.

INDEX TO VOLUME XXXIV

[NOTE.—In this index the titles of principal papers and the headings of departments, as *Discussions* are in italics.]

Abstracts—

Anthracite development in the Crested Butte district, Colorado (Dapples), 126

Capillary phenomena in oil reservoirs (Plummer and Livingston), 942

Cuneiform fragments diagnostic of fault breccia (White), 945

Discontinuities of the mineral sequence in the San Juan mining districts, Colo. (Burbank), 129

Dry polishing of mineragraphic specimens (Fraser and von Heune), 467

Experimental study of some physical characteristics of certain ore-bearing limestones (Rove), 128

Galena-sphalerite deposit in northeast Alabama (Andrews), 945

Genesis of the ferberite and gold telluride ores of Boulder County, Colorado (Lovering), 939

Genetic correlation of cinnabar and some gold-silver deposits (Fraser), 468

Geologic parallels: Hog Mountain, Alabama and Paracale, Philippine Islands (Wisser), 127

Geologic significance of minor elements in sphalerite (Stoiber), 136

Geological occurrence and practical relations of water, gas and oil encountered in driving the Claremont tunnel through the Berkeley Hills (Louderback), 469

Geology, mineralization, and placers of Tarryall and Beaver Creeks Park County, Colorado (Singewald), 132

Geology and development of the Mill Close mine, Derbyshire, England (Traill), 134

Geology and development of the Polaris-Taku mine (Sharpstone), 127

Geology and ground-water resources of the "Equus Beds" area in south-central Kansas (Lohman and Frye), 942

Abstracts—Continued

Geology and vein systems of the Cripple Creek district, Colo. (Koschmann), 947

Geology in a litigation case (Moore), 942

Geology of Hiwassee dam site (Moneymaker), 137

Geology of the Canadian Malartic gold mine (Derry), 138

Geology of the Ropes gold mine, Marquette County, Michigan (Broderick), 939

Geophysics supplementing geological examinations (Lundberg), 125

Ground water in the Oklahoma Panhandle (Schoff), 942

Ground-water conditions of the Dakota sandstone in northwestern Iowa (Robinson), 940

High temperature—intermediate pressure molybdenite deposit at Rencontre East, Newfoundland (White and Sampson), 133

Manganese deposits in the Olympic Peninsula, Washington (Park), 944

Manganese in a thermal spring deposit in west-central Utah (Thomas and Callaghan), 130

Mineral deposition at Steamboat Springs, Nevada (Gianella), 471

Mineral paragenesis at Leadville, Colorado (Chapman), 135

Nickel deposit near Gold Hill, Colorado (Goddard and Lovering), 131

Nomenclature of the megascopic description of Illinois coals (Cady), 134

Origin and differentiation of the major acid intrusives of the Rouyn-Bell River area, northwestern Quebec (Güssow), 131

Origin of the magnetic iron ores in the Lyon Mtn. region, N. Y. (Miller), 947

Outcrops of ore shoots (Schmitt), 135

Pegmatites of the Keystone area (Apsouri), 943

Abstracts—Continued
Pre-Cambrian iron mineralization in southeast Missouri (Tolman and Meyer), 946
Preliminary account of the geology of a portion of the Lupa goldfield, Tanganyika, Africa (Gallagher), 128
Preliminary notes on the relation of Philippine mining districts to the structural history of the Archipelago (Wisser), 468
Preliminary report on the ore deposits of the Chichagof mining district, Alaska (Reed), 126
Quicksilver deposits of the Terlingua region, Texas (Ross), 125
Radioactivity of sedimentary rocks and associated petroleum (Goodman, Bell, and Whitehead), 941
Relation of orebodies to rock structure in the Interstate mine, Wallace, Idaho (McKinstry and Svendsen), 137
Salt water intrusion: A coastal ground-water problem (Barksdale), 129
Significance of bornite-chalcocite microtextures (Schwartz), 135
Some features of quicksilver deposits in and near Lake County, California (Ross), 467
Some geological features of Kolar, Porcupine, and Kirkland Lake (Dougherty), 137
State mineral survey in Arkansas (Branner), 941
Structural control and form of oreshoots in the southern Appalachian gold deposits (Park), 470
Structural control in European lead-zinc ores of the Mississippi Valley type (Behre), 944
Structural control of ore deposition: The effects of mineral sequence (Hulin), 471
Structural relations of chromite deposits (Sampson), 130
Structural relations of some gold deposits between Lake Nipigon and Long Lac, Ontario (Bruce), 133
Study of the Hedley mill products (Warren and Madsen), 128
Thermodynamical approach to the flow of ground water (Hubbert), 946
Use of International Business Machine methods in recording coal data (Cady and Boley), 940

Abstracts—Continued
Vein solutions and rock alteration in the Boulder County tungsten district of Colorado (Lovering), 132
Adams, F. D., review of book by, 584
Adirondack magnetite deposits, Metasomatic origin of the (Alling), 141
Africa, stratigraphic lexicon (review), 237
Aikenite, 754, 761
Alabama, and Paracale, Philippine Islands, Geologic parallels: Hog Mountain (Wisser), 297; (abstract), 127
The oolitic limestone deposits of Franklin County (Jones), 573
galena-sphalerite deposit (abstract), 945
Alabandite, 792, 799
Alaska, Chichagof district (abstract), 126
Algodonite, 754
Alkali sulphide solutions on minerals at elevated temperatures, Action of (Lindner and Gruner), 537
Alling, H. L., *Metasomatic origin of the Adirondack magnetite deposits*, 141–172
Allison, I. S., review of book by, 582
Alteration, Arbus district, Sardinia, 85
Bonanza King mine area, Nev., 102
Canadian Malartic Gold Mine, 497
Chuquicamata, Chile, 679
Contact Lake, N. W. T., 764
Day Dawn gold mine, New Guinea, 177
diabase, Ontario, 33
ferberite and gold veins, Colo. (abstract), 939
ilmenite, 931
Lupa gold field, Tanganyika, 263
Magnolia district, Colo., 443
metasomatism near gold deposits, W. Aust., 782
Quebec, Thetford district (review), 236
tungsten veins, Boulder Co., Colorado (abstract), 132
Wau-Edie Creek area, New Guinea, 898
Ambrose, J. W., on gold, 496
Amick, H. C., *Slates of east Tennessee*, 451–458
on peridotite, 196
Analyses (see Chemical analyses)
Andrews, T. G., abstract of paper by, 945

Annotated Bibliography of Economic Geology, Index (review), 464
Anthophyllite, 719
Anthracite, Anthracite-Crested Butte district, Colorado, 381; (abstract), 126
Anthraxylon, 484
Antimony-arsenic-sulphur system, 74
Apatite, 927
"Aplite," Cobalt, Ont., 32
Appalachians, gold, structure and form of deposits (abstract), 470
Apsouri, C. N., abstract of paper by, 943
Argentite, 106
Arizona, Manganese mineralization at Tombstone (Rasor), 790
Childs-Aldwinkle mine (review), 347
Mammoth area (review), 347
Arkansas, mineral survey (abstract), 941
Arnold-Bemrose, H. H., on limestone, 859
Arsenopyrite, 752
Asbestos, Quebec, Thetford district (review), 235
Asbestos and chromite deposits of Wyoming (Beckwith), 812
Attritus, 491
Australia, Central and West Australia (review), 353

Bailey, L. W., on Nova Scotia, 921
Bain, G. W., review by, 235
Balk, R., on flow structures, 302
on marble, 144
Bancroft, M. F., on manganese, 918
Barite, 335
Barite deposits, Origin of the Sweetwater, Tennessee (Laurence), 190
Barium, 915
Barksdale, H. C., abstract of paper by, 129
Barlow, A. E., on aplite, 14
Barrow, G., on Cornwall district, 12
Bascom, F., review of bulletin by, 239
Bastin, E. S., *The nickel-cobalt-native silver ore type*, 1–40
on gold, 25
on paragenesis, 399
on pitchblende, 24
on silver, 18
on texture, 414
Bateman, A. M., on chalcocite, 401, 405
on chrysotile, 838
reviews by, 351, 463, 584, 845, 846
Bateman, J. D., books received, 122, 239, 353, 465, 585, 735, 847
Baxter, C. H., review of book by, 462
Bayley, W. S., on sphalerite, 656
reviews by, 120, 121, 237, 238, 351, 352, 464, 584, 845, 933
Becke, F., on pitchblende, 22
Becker, G. F., on sulphides, 538
Beckwith, R. H., *Asbestos and chromite deposits of Wyoming*, 812–843
Behre, C. H., Jr., abstract of paper by, 944
review by, 582
Bell, J. F., *Notes on the uses of methyl methacrylate "Lucite" in a geological laboratory*, 804–811
Bell, J. M., on silver, 25
Bell, K. G., abstract of paper by, 941
Ben Day paper, 422
Berman, H., on chrysotile, 826
Bibliography, coal, nomenclature, 494
economic geology (review), 464
geology (review), 584
industrial chemicals, 296
Kolar, Porcupine and Kirkland Lake gold fields, 652
Mill Close Mine area, England, 888
outcrops of ore shoots, 672
sulphide compounds of copper, 232
Biotite, 158, 542
Bismuth, Colorado, Leadville ores (abstract), 135
Contact Lake, N. W. T., 761
nickel-cobalt-silver deposits, 20
Bismuthinite, 216, 761
Blanchard, R., on outcrops, 655
Block diagrams, Measurements in (Ives), 561
Shades and screens for isometric (Ives), 419
Bode, H., on coal, 384
Boley, C. C., abstract of paper by, 940
Bonanza King mine, Humboldt Range, Pershing County, Nevada, Geology of the (Campbell), 96
Books received, 122, 239, 353, 465, 585, 735, 847, 935
Bornite, 708, 752
Bornite-chalcocite microtextures, Significance of (Schwartz), 399; (abstract), 135
Boswell, P. F., on outcrops, 655
Bowen, N. L., on aplite, 14
on basalt, 168
on hypersthene, 149
on iron, 169
Branches or leakages, 656
Branner, G. C., abstract of paper by, 941

Breccia, Childs-Aldwinkle mine, Arizona (review), 348
Cripple Creek, Colo. (abstract), 947
diagnosis (abstract), 945
Breithaupt, —., on smaltite, 16
British Columbia, gold, Hedley mill products (abstract), 128
Polaris-Taku mine (abstract), 127
Broderick, T. M., abstract of paper by, 939
communication by, 581
Brögger, W. C., on bismuth, 21
Broken Hill lode, New South Wales, 604
Bruce, E. L., *Structural relations of some gold deposits between Lake Nipigon and Long Lake, Ontario*, 357–368
abstract of paper by, 133
Bubnoff, S. v., review of book edited by, 584
Buchrucker, L., on Leogang ore deposits, Germany, 16
Buddington, A. F., on mineral deposits, 112
review of bulletin by, 122
Buerger, N. W., on chalcopyrite, 106
Bull, A. J., on shading, 423
Burbank, W. S., abstract of paper by, 129
on folding, 373
Burrows, A. G., on veins, 14, 649
Butler, B. S., on bismuthinite, 21
on folding, 638
on manganese, 791
on texture, 112
reviews by, 347

Cady, G. H., *Nomenclature of the megascopic description of Illinois coals*, 475–494
abstracts of papers by, 134, 940
review by, 732
Cairnes, C., on manganese, 918
Calamine, 885
Calcite, 159, 838, 882, 927
"black calcite," 796
California, Claremont tunnel (abstract), 469
geologic map (review), 351
inclusions at Grass Valley (discussion), 343
mercury, Lake County (abstract), 467
Miocene (review), 584
Callaghan, E., review of bulletin by, 122
Callaghan, E., and Thomas, H. E., *Manganese in a thermal spring in west-central Utah*, 905–920
abstract of paper by, 130
Campbell, D. F., *Geology of the Bonanza King mine, Humboldt Range, Pershing County, Nevada*, 96–112
Canada, A silver-pitchblende deposit at Contact Lake area, Great Bear Lake area (Furnival), 739
geologic names (review), 122
nickel-cobalt-silver deposits, 12
Canadian Malartic Gold Mine, N. Quebec, The geology of the (Derry), 495
Cannel coal, 492
Carbonates, 334, 768, 826
manganese, 796
Carpenter, H. C. H., on silver, 763
Carruthers, R. G., on lead, 852
Cathcart, S. H., on Little Rocky Mtns., Mont., 202
Catlett, C., on iron carbonate, 335
Central America, geologic names (review), 122
Cerussite, 885
Cesaris, P. de, on copper, 54
Ceylon (review), 353
Chalcocite, 58, 110, 218, 709, 752
Chalcocite microtextures, Significance of bornite- (Schwartz), 399; (abstract), 135
Chalcopyrite, 106, 708, 752
Chalcostibite, 58
Chamosite, 284
Chapman, E. P., abstract of paper by, 135
Charlewood, G. H., on carbonates, 257
Chemical analyses—
alaskite, Lupa gold field, Tanganyika, 252
chromite, Wyo., 831
copper sulphide compounds, 64, 215
gold ore assays, Day Dawn mine, New Guinea, 176
Grenville rocks, Quebec, 715
hematite, Wichita Mtns., Okla., 283
limestone, Mill Close Mine, England, 881
magnetite, 926
Wichita Mountains, Oklahoma, 277
manganese, Utah, 130, 915
pitchblende, Contact Lake, N. W. T., 754
rocks, Arbus district, Sardinia, 86
Chuquicamata, Chile, 682
slate, Tennessee, 457
waters, Abraham Hot Springs, Utah, 910

Chemical industries, Mineral resources of the (Keller and Quirke), 287
Chile, S. A., The primary mineralization at Chuquicamata (López), 674
Chlorite, 502, 543, 765
Chromite, Quebec, Thetford district (review), 236
structure of chromite deposits (abstract), 130
Chromite deposits of Wyoming, Asbestos and (Beckwith), 812
Chrysotile, 825
Church, J. A., on manganese, 798
Cinnabar, California, Lake County (abstract), 467
gold-silver and cinnabar deposits (abstract), 468
Clarain, 487
Clark, T. H., review of memoir by, 235
Clarke, E. de C., review of book by, 353
Clarke, E. de C., and Ellis, H. A., *Metasomatism of country near ore-bodies and its possible economic significance*, 777–789
Clays, Columbia River valley (review), 932
Coal, Illinois, megascopic description nomenclature (abstract), 134
origin (review), 732
recording data, methods (abstract), 940
Coal metamorphism in the Anthracite-Crested Butte Quadrangles, Colorado (Dapples), 369
Coals, Nomenclature of the megascopic description of Illinois (Cady), 475
Cobalt, Colorado, Gold Hill area (abstract), 131
Contact Lake, N. W. T., 759
Cobaltite, 760
Cobalt-native silver ore type, Nickel- (Bastin), 1
Coke, natural coke, 382
Coleman, A. P., on cobalt, 19
Collier, A. J., on Little Rocky Mtns., Mont., 202
Collins, W. H., on aplite, 14
on Cobalt series, 30
Colony, R. J., on magnetite, 143
Colorado, Coal metamorphism in the Anthracite-Crested Butte Quadrangles (Dapples), 369; (abstract), 126
Telluride-tungsten mineralization of the Magnolia mining district (Wilkerson), 437
Colorado—Continued
Cripple Creek district (abstract), 947
Gilman district, 662
gold, Tarryall and Beaver Creeks placer deposits (abstract), 132
gold tellurides and ferberite (abstract), 939
Leadville ores, paragenesis (abstract), 135
nickel, Gold Hill area (abstract), 131
San Juan district, mineral sequence (abstract), 129
tungsten, Boulder County (abstract), 132
Conservation (review), 734
Contact Lake, Great Bear Lake area, Canada, A silver-pitchblende deposit at (Furnival), 739
Cooke, H. C., on silver, 671
review of memoir by, 235
Copper, Arizona, Childs-Aldwinkle mine (review), 347
bornite-chalcocite microtextures, 399; (abstract), 135
Chile, Chuquicamata deposit, 674
Colorado, Gold Hill area (abstract), 131
Contact Lake, N. W. T., 752
Michigan, 606
New Mexico, Lordsburg district (review), 731
New South Wales, sedimentary deposits (discussion), 113
nickel-cobalt-silver deposits, 2
Quebec, Montauban zone, 712
red bed deposits (discussion), 113
Tombstone, Ariz., 790
Copper with arsenic antimony and bismuth, The pyrosynthesis, microscope study and iridescent filming of sulphide compounds of (Gaudin and Dicke), 49, 214
Cordierite, 719
Corry, A. V., on gold, 201
Cotter, G. de P., review of book by, 353
Covellite, 57, 110, 225, 709
Crane, W. R., on sienna, 338
Crickmay, G. W., on Ocoee series, 452
Cross, W., on laccoliths, 374
Crowther, J. G., review of book by, 121
Currier, L. W., on zinc, 192

Dake, H. C., review of book by, 352
Dalmer, K., on the Erzgebirge, 8
Daly, R. A., on alaskite, 252
on dikes, 46
review of book by, 351

Dams, Hiwassee dam site, North Carolina (abstract), 137
Dana, E. S., on copper, 54, 214
Dapples, E. C., *Coal metamorphism in the Anthracite-Crested Butte Quadrangles, Colorado*, 369–398
abstract of paper by, 126
David, T. W. E., on copper, 113
Davis, H. T., on barite, 198
Dawson, J. W., on Nova Scotia, 921
Day, A. L., on springs, 916
Day Dawn mine, New Guinea, Ore geology of the (Fisher), 173
Derry, D. R., *The geology of the Canadian Malartic Gold Mine, N. Quebec*, 495–523
abstract of paper by, 138
on pegmatites, 48
Diagrams, Measurements in block (Ives), 561
Shades and screens for isometric block (Ives), 419
barite, Sweetwater district, Tennessee, 194
block diagram measurements, 562
copper sulphide systems, 65, 221
Day Dawn lode, New Guinea, 175
folds, Canadian Malartic Mine, Que., 509
limestone grain size and color, 660
metasomatism near gold deposits, W. Aust., 779
methyl methacrylate treatment apparatus, 807
Mount Carbon laccolith, Colorado, 375
ore production, Mill Close Mine, England, 857
paragenesis, Adirondack magnetite deposits, 164
rock alteration changes, Chuquicamata, Chile, 687
Dicke, G., with Gaudin, A. M., *The pyrosynthesis, microscope study and iridescent filming of sulphide compounds of copper with arsenic, antimony and bismuth*, 49–81, 214–232
Dictionary, German-English thesaurus (review), 845
Dikes, Arbus district, Sardinia, 87
asbestos and chromite deposits, Wyoming, 824
Bonanza King mine area, Nev., 101
Canadian Malartic Gold Mine, Quebec, 498
Cornwall, England, 11
Cripple Creek, Colo. (abstract), 948
Dikes—*Continued*
Kolar, Porcupine, and Kirkland Lake, 639
Lupa gold field, Tanganyika, 251
Magnolia district, Colorado, 439
Newfoundland, Rencontre East molybdenite deposit (abstract), 133
Nipigon and Long Lakes district, Ontario, 360
Ruby Gulch gold district, Montana, 207
Wichita Mtns., Oklahoma, 273
Dikes and ore deposits, Diaschistic (Spurr), 41
Diller, J. S., on asbestos, 816, 822
on chromite, 830
Discussion and communications—
Alteration of ilmenite (Merritt), Koenigsberger, 844; (Koenigsberger), Moore, 931
Dislocated inclusions in gold-quartz veins at Grass Valley, California (Farmin), Wiebenga, 343; (Farmin), Douglas, 727
The gold Missus (Fowler-Lunn), Hirst, 460
Magnetic surveys in Michigan copper country (Lamey), Broderick, 581
Magnetite crystals from meteoric solutions (Spiroff), Gruner, 342
Sedimentary deposits of copper, vanadium, uranium and silver in southwestern United States (Fischer), Raggatt, 113
The Seventh Assembly, International Union of Geodesy and Geophysics, Washington, D. C., Sept. 4–15, 1939, 233
Texas surface soils (Tanner), 459
Doelter, C., on magnesioferrite, 926
on stilbite, 387
on sulphides, 538
Donnay, J. D. H., on texture, 414
Dorffel, D., on cobalt, 17
Dougherty, E. Y., *Some geological features of Kolar, Porcupine and Kirkland Lake*, 622–653
abstract of paper by, 137
on gold, 789
Douglas, C. B. E., discussion by, 727
Drabble, G. C., on fluorspar, 852
Dunnington, F. P., on manganese, 802
Durain, 488
Dyson, J. L., *Ruby Gulch gold mining district, Little Rocky Mountains, Montana*, 201–213.

Earth, architecture (review), 351
internal constitution (review), 847
magnetism and electricity (review), 934
Earthquakes (review), 934
Eckel, E. B., on block diagram, 420
Economic geology, index (review), 464
Edmundson, R. S., on barite, 198
Efremov, J. A., on copper, 114
Eichrodt, C. W., on molybdenum, 703
Ellestad, R. B., analysis by, 926
Ellis, H. A., with Clarke, E. de C., *Metasomatism of country near ore-bodies and its possible economic significance*, 777–789.
Ellsworth, H. V., on pitchblende, 23
Emmons, S. F., on sulphides, 538
Emmons, W. H., on carbonated waters, 800
on gold, 201
on manganese, 801
on mineralization, 668
on silver, 110
reviews of books by, 116, 582
Enargite, 71, 707
England, Cornwall nickel-cobalt deposits, 11
Mill Close mine, 851; (abstract), 134
English, G. L., review of book by, 734
English, S. G., analyses by, 277
Enrichment, Bonanza King mine area, Nev., 110
Day Dawn gold mine, New Guinea, 187
Lupa gold field, Tanganyika, 262
nickel-cobalt-silver deposits, 24
telluride-tungsten ores, Colo., 445
Eppson, H. F., analyses by, 831
Erdmann, E., on coal, 384
Ericksson, O. S., on cobalt, 17
Eskola, P., on Orijarvi, Finland, 724
Ettlinger, I. A., on texture, 417
Europe, lead-zinc deposits (abstract), 944
Experiments, alkali sulphide solutions, 540
copper-antimony-sulphur system, 55
limestones, ore-bearing (abstract), 128
Extramensurate ore bodies, 596, 617

Fahey, J. J., analysis by, 915
Famatinite, 58
Farey, J., on limestone, 857
Farmin, R., discussion of paper by, 343
on inclusions, 727
Faults, Bonanza King mine area, Nev., 104
Cripple Creek, Colo. (abstract), 948
Day Dawn gold mine, New Guinea, 180
Kolar, Porcupine, and Kirkland Lake gold fields, 636
Lupa district, Tanganyika, 243
Magnolia district, Colo., 440
Mill Close Mine area, England, 863
Philippine Islands, mining districts and structural history of Islands (abstract), 468
Ruby Gulch gold district, Montana, 208
Sweetwater barite district, Tennessee, 192
Tombstone, Ariz., 791
Wau-Edie Creek area, New Guinea, 895
Fayalite, 542
Fearnsides, W. G., on Derbyshire, 857
Feigl, F., review of book by, 464
Feldspar, 149, 454, 692
Feldtmann, F. R., on metasomatism, 783
Fenner, C. N., on basalt, 168
Ferguson, H. G., on gold, 619
Filming of sulphide compounds of copper with arsenic, antimony and bismuth, The pyrosynthesis, microscope study and iridescent (Gaudin and Dicke), 49, 214
Fischer, R. P., discussion of article by, 113
Fisher, L. W., on chromite, 830
Fisher, N. H., *Metasomatism associated with Tertiary mineralization in New Guinea*, 890–904
Ore geology of the Day Dawn mine, New Guinea, 173–189
Flaherty, G. F., on folding, 507
Fleener, F. L., review of book by, 352
Fleming, J. A., review of book edited by, 934
Fletcher, A. R., on mineralization, 870
Flett, J. A., on cordierite, 725
Fluorite, 159, 193, 210, 883
Folding, Anthracite-Crested Butte district, Colorado, 372
Canadian Malartic Gold Mine, 506
Kolar, Porcupine, and Kirkland Lake gold fields, 636
Mill Close Mine area, England, 862
Montauban zone, Quebec, 715
Philippine Islands, mining districts and structural history of Islands (abstract), 468
Ford, W. E., on copper, 54, 214

Foreman, F., on pyrite, 538
Foster, M. D., analyses by, 910
Fractures, Canadian Malartic Gold Mine, 507
Hog Mtn., Ala., Paracale, Philippines, 302
Fraser, H. J., abstracts of papers by, 467, 468
Freeman, H., on sulphides, 538
Friedensburg, F., review of book by, 464
Frye, J. C., abstract of paper by, 942
Furnival, G. M., *A silver-pitchblende deposit at Contact Lake, Great Bear Lake area, Canada*, 739–776
Fusain, 477

Galena, 91, 336, 671, 760, 882, 945
Gallagher, D., *A preliminary account of the geology of a portion of the Lupa goldfield*, 243–267
abstract of paper by, 128
books received, 935
on magnetite, 142
Gannett, R. W., on gold, 619
Garner, F. H., review of book edited by, 933
Garnet, 158, 542
Gaudin, A. M., and Dicke, G., *The pyrosynthesis, microscope study and iridescent filming of sulphide compounds of copper with arsenic, antimony and bismuth*, 49–81, 214–232
Geijer, P., on textures, 406
Genesis, cupriferous red bed deposits (discussion), 113
Day Dawn gold lode, New Guinea, 181
ferberite and gold telluride, Colorado (abstract), 939
gold, Canadian Malartic Gold Mine, 520
Kolar, Porcupine and Kirkland Lake, 648
New Guinea, 897
Ruby Gulch deposits, Montana, 212
lead-zinc deposits, Arbus district, Sardinia, 93
Mill Close Mine ores, England, 887
nickel-cobalt-silver deposits, 19
silver-pitchblende ores, Contact Lake, N. W. T., 772
titanite (discussion), 844
Geologic maps—
Anthracite-Crested Butte district, Colorado, 373
Geologic maps—*Continued*
Arbus district, Sardinia, 83
asbestos and chromite deposits, Wyoming, 817
Bonanza King mine area, Nev., 99
California (review), 351
Cartersville district, Georgia, 327
Contact Lake, N. W. T., 743
gold deposits, Mysore and Ontario, 624
Hog Mtn., Ala., and Paracale, Philippines, 301
Maturin Basin, Venezuela, 526
pre-Cambrian shield, Canada, 498
Ruby Gulch gold district, Montana, 204
Wau-Edie Creek area, New Guinea, 892
Wichita Mtns., Okla., 281
Geologic parallels: Hog Mountain, Alabama, and Paracale, Philippine Islands (Wisser), 297
Geological factors in the valuation of mines (McLaughlin), 589
Geological features of Kolar, Porcupine and Kirkland Lake, Some (Dougherty), 622
Geology, Abraham Hot Spring dome, Utah, 908
Anthracite-Crested Butte Quadrangles, Colorado, 369
bibliography (review), 584
Cartersville district, Georgia, 326
Colorado, Tarryall and Beaver Creeks placer deposits (abstract), 132
Contact Lake, N. W. T., 741
Cripple Creek area, Colo. (abstract), 947
England, Mill Close mine (abstract), 134
historical (review), 121
history (review), 584
India, Ceylon, and West Australia (review), 353
Kansas, Equus beds area (abstract), 942
Lake Nipigon and Long Lake region, Ontario, 357
litigation case (abstract), 942
Little Rocky Mountains, Montana, 202
Lordsburg district, N. M. (review), 731
Magnolia district, Colorado, 438
Maturin Basin, Venezuela, 525
molybdenite deposits (review), 347
Newfoundland, Rencontre East molybdenite deposit (abstract), 133

Geology—*Continued*
nickel-cobalt-silver deposits, 8
North Carolina, Hiwassee dam site (abstract), 137
Nova Scotia, southern, 922
oolitic limestone, Alabama, 574
Pennsylvania, Honeybrook and Phoenixville Quadrangles (review), 239
Polaris-Taku mine, British Columbia (abstract), 127
Quebec, Montauban zone, 713
Thetford district (review), 235
Ropes gold mine, Michigan (abstract), 939
source book (review), 847
Sweetwater barite deposits, Tennessee, 190
textbook (review), 582
Wau-Edie Creek area, New Guinea, 890
Western Australia, 781
Wichita Mountains, Oklahoma, 269
Geology and development of Mill Close Mine, Derbyshire (Traill), 851
Geology of a portion of the Lupa goldfield, A preliminary account of the (Gallagher), 243
Geology of the Arbus area in Sardinia, Italy, The lead-zinc ore deposits and (Wright), 82
Geology of the Bonanza King mine, Humboldt Range, Pershing County, Nevada (Campbell), 96
Geology of the Canadian Malartic Gold Mine, N. Quebec (Derry), 495
Geology of the Day Dawn mine, New Guinea, Ore (Fisher), 173
Geomorphology, textbooks (reviews), 734, 846
Geophysics and geological examinations (abstract), 125
Georgia, Sienna ("ocher") deposits of the Cartersville district (Kesler), 324
German-English dictionary (review), 845
Germany, Erzgebirge nickel-cobalt deposits, 8
Gianella, V. P., abstract of paper by, 471
Gibson, W., on lead, 852
Gilbert, G., on chalcocite, 111
Gilbert, G. K., on intrusions, 374
on springs, 907
Gillson, J. L., on cordierite, 724
Glass (review), 120
Goddard, E. N., abstract of paper by, 131
on ores, 447
Gold, 43
Alaska, Chichagof district (abstract), 126
Appalachian deposits, structure (abstract), 470
Bonanza King mine, Nev., 105
British Columbia, Hedley mill products (abstract), 128
Polaris-Taku mine (abstract), 127
Childs-Aldwinkle mine, Arizona (review), 347
cinnabar and gold-silver deposits (abstract), 468
Colorado, Cripple Creek (abstract), 947
ferberite and gold tellurides (abstract), 939
Leadville ores (abstract), 135
San Juan district, mineral sequence (abstract), 129
Tarryall and Beaver Creeks placer deposits (abstract), 132
Day Dawn mine, New Guinea, 173
Hog Mtn., Ala., Paracale, Philippines, 310; (abstract), 127
inclusions at Grass Valley, Calif. (discussion), 343
Kolar, Porcupine, and Kirkland Lake, 622; (abstract), 137
Mammoth district, Arizona (review), 347
metasomatism near W. Aust. deposits, 777
Michigan, Ropes mine (abstract), 939
New Guinea, Wau-Edie Creek area, 890
Ontario, Lake Nipigon-Long Lac zone (abstract), 133
outcrops at Goldfield, Nev., 663
Quebec, Canadian Malartic Gold Mine, 495; (abstract), 138
Montauban zone, 712
(review), 116
Tanganyika, Lupa district (abstract), 128
Witwatersrand field, 607
Gold deposits between Lake Nipigon and Long Lake, Ontario, Structural relations of some (Bruce), 357
Gold mining district, Little Rocky Mountains, Montana, Ruby Gulch (Dyson), 201

Goldfield, A preliminary account of the geology of the Lupa (Gallagher), 243
Goodale, C. W., on manganese, 799
Goodman, C., abstract of paper by, 941
Gordon, C. H., on barite, 190
Gossans, 654
Grantham, D. R., on Lupa district, Tanganyika, 244
Graphite, 159
Graton, L. C., *Waldemar Lindgren*, 850a
on chalcocite, 111, 404
on fissures, 637
on valuation, 592
review by, 116
Green, A. H., on lead, 852
Greenockite, 885
Gregory, J. W., on faults, 243
Griggs, D. T., on fracturing, 310
Gropp, W., on coal, 384
Groves, A. W., review of book by, 238
Gruner, J. W., communication by, 342
on iron, 602
on magnetite, 343
on solutions, 537
Gruner, J. W., with Lindner, J. L., *Action of alkali sulphide solutions on minerals at elevated temperatures*, 537–560
Güssow, W. C., abstract of paper by, 131
Gunning, H. C., on gold, 496
Gutenberg, B., review of book edited by, 847

Hague, A., on Humboldt Range, Nev., 96
Hall, D. A., on textures, 408
Hall, G. M., on peridotite, 196
Hancox, E. G., on anhydrite, 641
Hanson, G., on manganese, 918
Harder, E. C., on iron, 459
on manganese, 918
Harker, A., on cordierite, 723
Harper, L. F., on copper, 113
Hastingsite, 146
Hatch, F. H., on Kolar district, Mysore, 635
Haughton, S. H., review of book by, 237
Hawaii, geologic names (review), 122
Haycock, M. H., on pitchblende, 775
Hayes, A. O., on oolites, 284
Hayes, C. W., on Cartersville district, Ga., 326
on faults, 453
on Ocoee series, 452
Hecht, F., analysis by, 754
Hematite, 155, 543, 751, 946
specular, 702
Wichita Mtns., Okla., 282
Hematite veins in Triassic lavas of Nova Scotia, Magnetite and (Hornor), 921
Hendricks, T. A., on carbonization, 384
Hess, H. H., on serpentinization, 830, 842
Hetaerolite, 792
Hewett, D. F., on calcite, 798
on manganese, 799, 911, 919
on outcrops, 669
Hibben, J. H., on plastics, 807
Hickling, G., on coal, 384
Hill, J. B., on minette dikes, 11
Hill, J. M., on pitchblende, 24
Hirst, T., discussion by, 460
History of geology (review), 584
Hodge, E. T., review of book by, 932
Hoffman, E., on semi-fusain, 478
Hoffman, M. G., on Wichita Mtns., Okla., 269
Hohl, C. D., on magnetic surveys, 581
Holmes, A., on pitchblende, 450
Holmquist, P. J., on folding, 715
Hoover, H., on valuation, 591
Hoover, T. J., on valuation, 592
Hore, R. E., on aplite, 14
Hornor, A. P., Jr., *Magnetite and hematite in Triassic lavas of Nova Scotia*, 921–930
Horsch, S. M., on solutions, 539
Horwood, C. B., on cobalt, 17
Hoskold, H. D., on valuation, 591
Hubbert, M. K., abstract of paper by, 946
Huebner, W., review of book by, 845
Hughes, H. H., review of book edited by, 934
Hulin, C. D., abstract of paper by, 471
on metallization, 43
on veins, 321
Hull, J. P. D., on barite, 199
on sienna, 338
Humery, —., on pitchblende, 24
Hungary, Dobschau ore deposit, 15
Hurst, M. E., on fissures, 637
Hypersthene, 149

Idaho, Interstate mine (abstract), 137
Illing, V. C., on eastern Venezuela, 526
Illinois, coal, nomenclature of megascopic description (abstract), 134
Illinois coals, Nomenclature of the megascopic description of (Cady), 475

Ilmenite, 157, 277
alteration (discussion), 844, 931
Inclusions, Grass Valley, Calif. (discussion), 343
Inclusions in veins (discussion), 727
India, gold, Kolar, Porcupine and Kirkland Lake deposits (abstract), 137
Kolar field, 622
(review), 353
Industrial chemicals, 288
International Union of Geodesy and Geophysics, Washington Meeting (communication), 233
Iowa, ground water, northeastern Iowa (abstract), 940
Iron, Fire King asbestos deposit, Wyo., 817
magnetite, Adirondacks, 141
Missouri, southeast (abstract), 946
Texas surface soils (communication), 459
Iron ore deposits, 601
Iron ores of the Wichita Mountains, Oklahoma (Merritt), 268; (discussion), 844
Italy, The lead-zinc ore deposits and geology of the Arbus area in Sardinia (Wright), 82
nickel-cobalt-silver deposits, Sardinia, 16
Ives, R. L., *Measurements in block diagrams*, 561–572
Shades and screens for isometric block diagrams, 419–436

Jackson, G. C. A., on chalcocite, 405
James, W. F., on gold, 496
Jasperoid, 336, 661
Jenkins, O. P., review of map by, 351
Jenney, C. P., on Humboldt Range, Nev., 96
Johnston, W. D., Jr., on block diagrams, 419, 562
Jointing, Hog Mtn., Ala., Paracale, Philippines, 302
Mill Close Mine area, England, 863
Jones, E. L., Jr., on manganese, 918
Jones, W. B., *The oolitic limestone deposits of Franklin County, Alabama*, 573–580
Jongmans, W. J., on fuso-vitrain, 478
Junner, N. R., on veins, 42

Kania, J., on cordierite, 724
Kansas, Equus Beds area (abstract), 942
Keep, F. E., on asbestos, 837
Keil, K., on nickel-cobalt veins, 8
Keith, A., on Ocoee series, 452
Keller, R. N., and Quirke, T. T., *Mineral resources of the chemical industries*, 287–296
Kemp, J. F., on magnetite, 142, 171
Kentucky, barite, 199
Kesler, T. L., *Sienna ("ocher") deposits of the Cartersville district, Georgia*, 324–341
Kidd, D. F., on Great Bear Lake area, 741
on pitchblende, 775
on pitchblende-silver deposit, 15
King, C., on Humboldt Range, Nev., 96
Kirk, C. T., on mineralization, 698
Kirkland Lake, Some geological features of Kolar, Porcupine and (Dougherty), 622
Klaprothite, 223
Kleinpell, R. M., review of book by, 584
Klemm, G., on Nieder-Ramstadt district, Germany, 16
Klockmann, F., on copper, 54
Knight, C. W., on faults, 13
on ore deposits, 638
on silver, 26, 35
Knight, H. G., on plastics, 807
Knopf, A., on gold, 259
on Humboldt Range, Nev., 96
Kobell, F. von, on stylotypite, 54
Kolar, Porcupine and Kirkland Lake, Some geological features of (Dougherty), 622
Koopmans, R. G., on fuso-vitrain, 478
Koschmann, A. H., abstract of paper by, 947
Krieger, P., on silver, 18
review by, 731
Krüpe, E., on semi-fusain, 478
Kubiëna, W. L., review of book by, 238
Kühlwein, F. L., on semi-fusain, 478
Kugler, H. G., on eastern Venezuela, 526
Kuhn, T. H., review of bulletin by, 347

LaForge, L., on sienna, 338
Laird, H. C., on veins, 359
Lamey, C. A., on magnetic survey, 581
Landes, K. K., on pegmatites, 162
Laney, F. B., on intergrowths, 406
Langford, G. B., on anhydrite, 641
Larsen, E. S., on chrysotile, 826
on magmas, 377
Lasky, S. G., on silica, 662
review of bulletin by, 731

Launay, L. de, on pitchblende, 24
Laurence, R. A., *Origin of the Sweetwater, Tennessee, barite deposits*, 190–200
Lead, Alabama, galena-sphalerite deposit (abstract), 945
Colorado, Leadville ores, paragenesis (abstract), 135
San Juan district, mineral sequence (abstract), 129
England, Mill Close Mine, 851; (abstract), 134
European deposits (abstract), 944
Quebec, Montauban zone, 712
Tombstone, Ariz., 790
Lead-zinc ore deposits and geology of the Arbus area in Sardinia, Italy (Wright), 82
Ledoux, A. R., on cobalt, 20
Lee, A. W., review of book edited by, 934
Lee, W. T., on coal, 370
on springs, 911
Leet, L. D., review of book by, 463
Legraye, M., on coal, 385
Leith, C. K., on iron, 602
review of book by, 239
Leitmeier, —., on magnesioferrite, 926
Lessing, R., on anthracite, 385
Lettering of diagrams, 434
Leucoxene, 931
Lewis, E., on coal, 384
Lime, Columbia River valley (review), 932
Limestone, Columbia River valley (review), 932
grain size and color, 659
ore-bearing limestones (abstract), 128
Limestone deposits of Franklin County, Alabama, The oolitic (Jones), 573
Lincoln, F. C., on silver, 32
Lindgren, Waldemar (Graton), 850a
on carbonate, 335
on chalcocite, 111
on fissures, 346
on gold, 259, 619, 640
on manganese, 918
on textures, 406
Lindner, J. L., and Gruner, J. W., *Action of alkali sulphide solutions on minerals at elevated temperatures*, 537–560
Little Rocky Mountains, Montana, Ruby Gulch gold mining district (Dyson), 201
Livingston, H. K., abstract of paper by, 942
Lobeck, A. K., on block diagrams, 436, 561
review of book by, 846
Locke, A., on outcrops, 655
on textures, 408
Lockrey, A. J., on plastics, 811
Lohman, S. W., abstract of paper by, 942
Lombard, R. H., on chalcocite, 58
López, V. M., *The primary mineralization at Chuquicamata, Chile, S. A.*, 674–711
Louderback, G. D., abstract of paper by, 469
on Humboldt Range, Nev., 96
Lovering, T. S., abstracts of papers by, 131, 132, 939
on Front Range, Colo., 440
on heat, 386
on laccoliths, 377
review by, 462
"Lucite" in a geological laboratory, Notes on the uses of methyl methacrylate (Bell), 804
Lundberg, H., abstract of paper by, 125
Lupa goldfield, A preliminary account of the geology of a portion of the (Gallagher), 243
Luquer, L. McI., on alabandite, 792
Luzonite, 71

MacAlister, D. A., on Cornwall district, 11
McCallie, S. W., on iron carbonate, 335
McCaskey, H. D., on quartz, 312
McFarlane, G. C., on coal, 385
Mackay, R. A., on gold, 261
McKinstry, H. E., abstract of paper by, 137
on fissures, 637
McLaughlin, D. H., *Geological factors in the valuation of mines*, 589–621
communication by, 233
on chalcocite, 403
Madsen, C., abstract of paper by, 128
Magnesioferrite, 926
Magnesite, Columbia River valley (review), 932
Magnetic surveys, Michigan (communication), 581
Magnetite, 543, 751, 783, 816, 946
crystals from meteoric solutions, 342
Wichita Mountains, Oklahoma, 274
Magnetite and hematite veins in Triassic lavas of Nova Scotia (Hornor), 921

Magnetite deposits, Metasomatic origin of the Adirondack (Alling), 141
Mallet, J. W., on limestone, 573
Manganese, Day Dawn gold mine, New Guinea, 177
(review), 238
Utah, spring deposit (abstract), 130
Washington, Olympic Peninsula (abstract), 944
Manganese in a thermal spring in west-central Utah (Callahan and Thomas), 905
Manganese mineralization at Tombstone, Arizona (Rasor), 790
Mantos, 869
Maps (see also Geologic maps) —
Alabama limestone deposits, 574
barite and zinc deposits, Tennessee, 197
Chuquicamata, Chile, 678
Magnolia district, Colorado, 438
Mill Close Mine, England, 853
Ontario, 358
Tennessee, Ocoee series, 452
Utah, 906
Wau and Edie Creek, New Guinea, 891
Western Australia, 780
Wyoming, pre-Cambrian rocks, 814
Marcasite, 454
Marshall, C. E., review of book by, 732
Martite, 153
Mason, S. L., review of book by, 847
Mather, K. F., review of book by, 847
Matthews, J. W., review of translation by, 464
Mawdsley, J. B., on gold, 496
Meen, V. B., on quartz, 647
Megascopic description of Illinois coals, Nomenclature of the (Cady), 475
Meinzer, O. E., on springs, 907
Mercury, California, Lake County (abstract), 467
Texas, Terlingua region (abstract), 125
Merritt, C. A., *The iron ores of the Wichita Mountains, Oklahoma*, 268–286; (discussion), 844
Merwin, H. E., on chalcocite, 58
Mees, C. E. K., on reducer, 421
Mesabi Iron Range, 601
Metamorphism, coal, Colorado, Crested Butte district (abstract), 126
Metamorphism in the Anthracite-Crested Butte Quadrangles, Colorado, Coal (Dapples), 369
Metasomatic origin of the Adirondack magnetite deposits (Alling), 141
Metasomatism, New Guinea, Wau-Edie Creek area, 898
Metasomatism associated with Tertiary mineralization in New Guinea (Fisher), 890
Metasomatism of country near ore-bodies and its possible economic significance (Clarke and Ellis), 777
Methyl methacrylate "Lucite" in a geological laboratory, Notes on the uses of (Bell), 804
Metaxite (picrolite), 833
Mexico, geologic names (review), 122
outcrops of ore shoots, 664
silver-cobalt ores, 18
Meyer, C., abstract of paper by, 946
Michigan, copper lodes, 606
gold, Ropes mine (abstract), 939
magnetic surveys (communication), 581
Micropedology (review), 238
Microscope study and iridescent filming of sulphide compounds of copper with arsenic, antimony and bismuth, The pyrosynthesis (Gaudin and Dicke), 49, 214
Microtextures, Significance of bornite-chalcocite (Schwartz), 399
Mill Close Mine, Derbyshire, The geology and development of (Traill), 851
Millenbach, J. P., on gold, 496
Miller, B. L., on veins, 48
Miller, W., *The relationship of structure to petroleum production in eastern Venezuela*, 524–536
Miller, W. J., abstract of paper by, 947
Milne, J., review of book by, 934
Mine examination (review), 462
Mineral resources of the chemical industries (Keller and Quirke), 287
Mineral resources of world (review), 464
Mineral valuations of future (review), 239
Mineralization, Hog Mtn., Ala., Paracale, Philippines, 310
Mineralization at Chuquicamata, Chile, S. A., The primary (López), 674
Mineralization in New Guinea, Metasomatism associated with Tertiary (Fisher), 890
Mineralization of the Magnolia mining district, Colorado, Telluride-tungsten (Wilkerson), 437

Mineralogy, Bonanza King mine, Nev., 105
Canadian Malartic Gold Mine, Quebec, 518
Chuquicamata, Chile, 702
Contact Lake, N. W. T., 747, 750
Lupa gold field, Tanganyika, 254
Magnolia district, Colo., 442
manganese ores, Tombstone, Ariz., 792
mercury deposits, Lake Co., Calif. (abstract), 467
Mill Close Mine, England, 882
Montauban zone, Quebec, 722
Ruby Gulch gold district, Montana, 209
Wau-Edie Creek gold lodes, New Guinea, 895
Minerals, new (review), 734
Minerals at elevated temperatures, Action of alkali sulphide solutions on (Lindner and Gruner), 537
Mines, Geological factors in the valuation of (McLaughlin), 589
Miocene of California (review), 584
Missouri, iron (abstract), 946
Molybdenite, 256, 704
Arizona, Childs-Aldwinkle mine (review), 347
Chuquicamata, Chile, 703
Mammoth district, Arizona (review), 347
Newfoundland, Rencontre East deposit (abstract), 133
New Mexico, Questa deposit (review), 347
Moneymaker, B. C., abstract of paper by, 137
on Ocoee series, 452
Montana, Ruby Gulch gold mining district, Little Rocky Mountains (Dyson), 201
Moore, E. S., abstract of paper by, 942
discussion by, 931
on diabase, 32
Morey, G. W., on silica, 697
review of book by, 120
Morse, H. S., on outcrops, 655
Moses, A. J., on alabandite, 792
on ettringite, 801
Müller, H., on pitchblende, 23
Murdoch, J., on chalcocite, 111, 404

Native silver, 762
Native silver ore type, Nickel-cobalt- (Bastin), 1
Natural resources, conservation (review), 734
Neelands, E. V., on gold, 496
Nepheline, 207
Nevada, Geology of the Bonanza King mine, Humboldt Range, Pershing County (Campbell), 96
Goldfield ore outcrops, 663
Steamboat springs (abstract), 471
Newfoundland, molybdenite, Rencontre East deposit (abstract), 133
New Guinea, Metasomatism associated with Tertiary mineralization in (Fisher), 890
Ore geology of the Day Dawn mine (Fisher), 173
Newhouse, W. H., on texture, 413
New Jersey, salt water intrusion in coastal areas (abstract), 129
Newland, D. H., on gneiss, 143
on martite, 154
New Mexico, Lordsburg district (review), 731
molybdenite, Questa deposit (review), 347
zinc, 655
New South Wales, copper-bearing sediments (discussion), 113
New York, Lyon Mtn. magnetite deposits (abstract), 947
salt water intrusion in coastal areas (abstract), 129
Nickel, Colorado, Gold Hill area (abstract), 131
Contact Lake, N. W. T., 759
Nickel-cobalt-native silver ore type (Bastin), 1
Niggli, P., on dikes, 44
Nolan, T. B., on block diagrams, 419, 562
Nomenclature, geologic names of North America (review), 122
Nomenclature of the megascopic description of Illinois coals (Cady), 475; (abstract), 134
North America, geologic names (review), 122
North Carolina, barite, 198
Hiwassee dam site (abstract), 137
Nova Scotia, Magnetite and hematite veins in Triassic lavas of (Hornor), 921

Oates, F., analysis by, 252
on granite, 252
("Ocher") deposits of the Cartersville district, Georgia, Sienna (Kesler), 324
Ogryzlo, S. P., on solutions, 537

Oklahoma, The iron ores of the Wichita Mountains (Merritt), 268
ground water in Panhandle (abstract), 942
Olivine, 149, 542
O'Neill, J. J., on gold, 496
Ontario, Structural relations of some gold deposits between Lake Nipigon and Long Lake (Bruce), 357
gold, Lake Nipigon and Long Lac zone (abstract), 133
Porcupine, Kirkland Lake and Kolar (India) deposits (abstract), 137
Porcupine and Kirkland Lake, 622
Oolites, hematite, Wichita Mtns., Okla., 284
Oolitic limestone deposits of Franklin County, Alabama (Jones), 573
Orcel, J., on hetaerolite, 792
Ore deposition, Hog Mtn., Ala., Paracale, Philippines, 312
structural control and mineral sequence (abstract), 471
Ore deposits, Diaschistic dikes and (Spurr), 41
Bonanza King mine, Nev., 105
cupriferous red bed deposits (discussion), 113
Magnolia district, Colo., 442
nickel-cobalt-native silver type, 1
Oregon, Cascade Range (review), 122
Ruby Gulch gold district, Montana, 209
valuation, 589
Ore deposits and geology of the Arbus area in Sardinia, Italy, The lead-zinc (Wright), 82
Ore deposits and ore supply, 597
Ore geology of the Day Dawn mine, New Guinea (Fisher), 173
Ore shoots, Outcrops of (Schmitt), 654
gold deposits of Appalachians (abstract), 470
Lupa gold field, Tanganyika, 261
outcrops (abstract), 135
Orebodies, Mill Close Mine, England, 867
Ore-bodies and its possible economic significance, Metasomatism of country near (Clarke and Ellis), 777
Oregon, metalliferous deposits, Cascade Range (review), 122
mineral utilization (review), 932
Ores of the Wichita Mountains, Oklahoma, The iron (Merritt), 268
Origin, Bonanza King ore deposit, Nev., 112
gold, Lupa district, Tanganyika, 265
magnetite, Lyon Mtn., N. Y. (abstract), 947
Wichita Mtns., Okla., 279
magnetite veins, Nova Scotia, 929
manganese in hot spring, Utah, 916
sienna, Cartersville district, Georgia, 339
telluride-tungsten ore, Colo., 445
Origin of the Adirondack magnetite deposits, Metasomatic (Alling), 141
Origin of the Sweetwater, Tennessee, barite deposits (Laurence), 190
Orpiment, 69
Osborne, F. F., *The Montauban mineralized zone, Quebec*, 712–726
Outcrops of ore shoots (Schmitt), 654; (abstract), 135
Overbeck, R. M., on bornite, 403
Oxidation, Bonanza King mine, Nev., 108

Palmer, C., on gold, 25
Paragenesis, Adirondack magnetite deposits, 163
barite deposits, southern Appalachians, 198
Chuquicamata, Chile, 710
Day Dawn gold mine, New Guinea, 182
Leadville, Colorado ores (abstract), 135
magnetite veins, Nova Scotia, 929
Mammoth district, Arizona (review), 350
Ruby Gulch gold ores, Montana, 211
San Juan district, Colo. (abstract), 129
silver-pitchblende ores, Contact Lake, N. W. T., 766
structural control and mineral sequence (abstract), 471
telluride-tungsten ores, Magnolia district, Colo., 442
Pardee, F. G., review of book by, 462
Pardee, J. T., on calcite, 798
on manganese, 918
Park, C. F., Jr., abstracts of papers by, 470, 944
on gold, 300
Parkins, A. E., review of book edited by, 734
Parks, R. D., review of book by, 462
Parravano, N., on copper, 54
Parsons, C. E., on lead, 852
Partimensurate ore bodies, 596, 605

Pattern fight, 425, 432
Pavlovitch, S., on hetaerolite, 792
Peale, A. C., on springs, 907
Pearce, R., on pitchblende, 23
Pearcite, 761
Pegmatites, Adirondacks, 161
  Canadian Malartic Gold Mine, Quebec, 502
  Cartersville district, Georgia, 333
  Casper Mtn., Wyo., 825
  South Dakota, Keystone area (abstract), 943
Pelletier, R. A., on gold, 608
Penhallegon, W. J., on barite, 190
Pennsylvania, Honeybrook and Phoenixville Quadrangles (review), 239
Penrose, R. A. F., Jr., on manganese, 918
Perry, E. L., on chrysotile, 835
Peterson, N. P., review of bulletin by, 347
Petroleum, capillarity in reservoirs (abstract), 942
  radioactivity of sediments and oil (abstract), 941
  (review), 121
  technology review, 933
Petroleum production in eastern Venezuela, The relationship of structure to (Miller), 524
Philippine Islands, Geologic parallels: Hog Mountain, Alabama, and Paracale (Wisser), 297; (abstract), 127
  mining districts and structural history (abstract), 468
Photomicrographs—
  bornite-chalcocite microtextures, 402
  chrysotile and chromite, Wyo., 827
  Chuquicamata rocks, Chile, 681
  coal, Illinois, 486
  coke, Colorado, 383
  copper sulphide compounds, 60, 222
  gold ores, Ruby Gulch, Montana, 210
  iron ore, Wichita Mtns., Okla., 283
  magnetite, Nova Scotia, 924
  manganese ores, Tombstone, Ariz., 793
  ore, Bonanza King mine, Nev., 107
  pitchblende-silver ore, Contact Lake, N. W. T., 756
  rocks and magnetite, Adirondacks, 148
  telluride-tungsten ores, Colo., 444
Physiography, textbook (review), 846
Picrolite (metaxite), 833
Piepoli, M. P., on veins, 17
Pipes, Childs-Aldwinkle mine, Arizona (review), 348
  Cripple Creek, Colo. (abstract), 947
Pirsson, L. V., on gneiss, 202
Pitchblende, 22
Pitchblende deposit at Contact Lake, Great Bear Lake area, Canada, A silver- (Furnival), 739
Placer deposits, 618
Plans—
  Abraham Hot Springs dome, Utah, 912
  Bonanza King mine, Nev., 103
  Canadian Malartic Gold Mine, Quebec, 499
  Little Long Lac mine, Ontario, 363
  Mill Close Mine, England, 855
Plastics in a geological laboratory, 804
Plenemensurate ore bodies, 596, 600
Plummer, F. B., abstract of paper by, 942
Polianite, 794
Polishing of mineragraphic specimens (abstract), 467
Porcelain rock, Chuquicamata, Chile, 699
Porcupine and Kirkland Lake, Some geological features of Kolar (Dougherty), 622
Powers, S., on Acadian Triassic, 921
Pratt, J. H., on asbestos, 828
Prescott, B., on replacement, 868
Pryor, T., on fissures, 637
Pseudomorphs, bornite-chalcocite microtextures, 407; (abstract), 136
  calcite after chrysotile, 838
  magnetite after hematite, 946
  ochre after molybdenite, 705
Psilomelane, 794
Pyrite, 106, 157, 182, 211, 256, 335, 515, 697, 706, 752, 883
Pyrolusite, 794
Pyrosynthesis, microscope study and iridescent filming of sulphide compounds of copper with arsenic, antimony, and bismuth (Gaudin and Dicke), 49, 214
Pyroxene, 146

Quartz, 105, 150, 211, 254, 310, 692, 706, 840, 925, 928
  inclusions at Grass Valley, Calif. (discussion), 343
Quartz minerals (review), 352
Quebec, The geology of the Canadian Malartic Gold Mine, N. (Derry), 495
  The Montauban mineralized zone (Osborne), 712

Quebec—Continued
asbestos, Thetford district (review), 235
gold, Canadian Malartic mine (abstract), 138
intrusives of Rouyn-Bell River area (abstract), 131
Quicksilver. See Mercury
Quirke, T. T., with Keller, R. N., *Mineral resources of the chemical industries*, 287–296

Raggatt, H. G., discussion by, 113
Raistrict, A., review of book by, 732
Ramdohr, P., on copper, 54
on Nieder-Ramstadt district, Germany, 16
on textures, 406
Rammelsberg, C. F., on copper, 54
Ransome, F. L., on Humboldt Range, Nev., 96
on manganese, 798
on outcrops, 663
Rasor, C. A., *Manganese mineralization at Tombstone, Arizona*, 790–803
Rastall, R. H., on batholiths, 871
Ravic, L. G., on silver, 670
Ray, J. C., on chalcocite, 408
Redlich, K. A., on Leogang ore deposits, Germany, 16
Reed, J. C., abstract of paper by, 126
Replacement, Adirondack magnetite deposits, 165
bornite-chalcocite, 401
Mill Close Mine, England, 879
Reviews—
About petroleum (Crowther), Bayley, 121
Annotated Bibliography of Economic Geology: General Index, vols. I–X, 1928–1938, 464
Annual reviews of petroleum technology (Garner), 933
Architecture of the earth (Daly), Bateman, 351
Bergwirtschaft der Erde. Bodenschätze, Bergbau und Mineralienversorgung der Einzelnen Länder (Friedensburg), Bayley, 464
Birth and development of the geological sciences (Adams), Bateman, 584
Childs-Aldwinkle mine, Copper Creek, Arizona (Kuhn), Butler, 347
Descriptive list of the new minerals, 1892–1938 (English), 734
Reviews—Continued
Earthquakes and other earth movements (Milne and Lee), 934
Examination of fragmental rocks (Tickell), Bayley, 352
Geological map of California (Jenkins), Bayley, 351
Geologische Jahresberichte (Bubnoff), Bayley, 584
Geology, principles and processes (Emmons, Thiel, Stauffer, and Allison), Behre, 582
Geology and allied sciences. Thesaurus and coordination of English and German specific and general terms, 845
Geology and mineral resources of the Honeybrook and Phoenixville Quadrangles, Penn. (Bascom and Stose), 239
Geology and ore deposits of the Lordsburg mining district, New Mexico (Lasky), Krieger, 731
Geology of the "Questa" molybdenite deposit, Taos County, New Mexico (Vanderwilt), Butler, 347
Geomorphology—An introduction to the study of landscapes (Lobeck), Bateman, 846
Gold deposits of the world (Emmons), Graton, 116
Internal constitution of the earth. Physics of the earth, VII (Gutenberg), 847
Lexicon de stratigraphie. Africa (Haughton), Bayley, 237
Lexicon of geologic names of the United States (Wilmarth), 122
Mammoth mining camp area, Pinal County, Arizona (Peterson), Butler, 347
Manganese (Groves), 238
Market for Columbia River hydroelectric power using Northwest minerals (Hodge), Scheid, 932
Metalliferous deposits of the Cascade Range, Oregon (Callaghan and Buddington), 122
Micropedology (Kubiëna), Bayley, 238
Mine examination and valuation (Baxter, Parks, and Pardee), Lovering, 462
Mineral valuations of the future (Leith), 239
Minerals Yearbook 1939 (Hughes), 934
Miocene stratigraphy of California (Kleinpell), 584

Reviews—Continued
Nature and origin of coal and coal seams (Raistrick and Marshall), Cady, 732
Our natural resources and their conservation (Parkins and Whitaker), 734
Outline of historical geology (Wells), Bayley, 121
Practical seismology and seismic prospecting (Leet), Bateman, 463
Properties of glass (Morey), Bayley, 120
Quartz family minerals (Dake, Fleener, and Wilson), 352
Regionale Geologie der Erde. Middle and West Australia (Clarke), 353
Regionale Geologie der Erde. The Indian Peninsula and Ceylon (Cotter), 353
Source book in geology (Mather and Mason), 847
Spot tests (Feigl), 464
Strategic mineral supplies (Roush), Bateman, 845
Terrestrial magnetism and electricity. Physics of the Earth, VIII (Fleming), 934
Textbook of geomorphology (Worcester), 734
Thetford, Disraeli, and eastern half of Warwick map areas, Quebec (Cooke and Clark), Bain, 235
Rickard, T. A., on veins, 17
Riley, C. S., on Great Bear Lake area, 741
Roberts, J., on anthracite, 384
on coal, 387
Robinson, H. S., on Great Bear Lake area, 741
Robinson, L. C., on barite, 199
Robinson, T. W., abstract of paper by, 940
Robson, W. T., on faults, 637
Rocks, fragmental (review), 352
Rogers, A. F., on mineralizers, 46
Roos, G., on telain, 485
Ross, C. P., abstracts of papers by, 125, 467
Ross, C. S., on chromite, 830
on feldspar, 694
Roush, G. A., review of book by, 845
Rove, O. N., abstract of paper by, 128
on manganese, 799
Ruby Gulch gold mining district, Little Rocky Mountains, Montana (Dyson), 201
Ruedemann, R., on magnetite, 171
Russell, I. C., on gravel, 104

Safford, J. M., on metamorphic rocks, 453
Salt water intrusion in coastal regions (abstract), 129
Sampson, E., abstracts of papers by, 130, 133
on asbestos, 815
on chromite, 830
Samuel, W., on Little Long Lac mine, Ontario, 362
Santmyers, R. M., on ocher, 326
Savage, W. S., on manganese, 800
Sawdon, W. A., on gas pressure, 531
Schairer, J. F., on hypersthene, 149
on iron, 169
Schaller, W., on pegmatites, 694
Scheid, V. E., review by, 932
Schmidt, C., on veins, 16
Schmitt, H., *Outcrops of ore shoots*, 654–673
abstract of paper by, 135
Schneiderhöhn, H., on copper, 54
on textures, 406
Schoff, S. L., abstract of paper by, 942
Schouten, C., on pyrrhotite, 538
Schuette, C. N., on mercury, 313
Schumacher, F., on Freiberg district, 10
Schwartz, G. M., *Significance of bornite-chalcocite microtextures*, 399–418
abstract of paper by, 135
on stromeyerite, 761
Scientific notes and news, 140, 242, 356, 473, 588, 737, 850, 949
Screens for isometric block diagrams, Shades and (Ives), 419
Secrist, M. H., on barite, 190
on block diagrams, 572
Sections—
Arbus district, Sardinia, 83
Bonanza King mine, Nev., 100
Canadian Malartic Gold Mine, Quebec, 499
Day Dawn gold mine, New Guinea, 179
gold deposits, Mysore and Ontario, 626
Little Long Lac mine, Ontario, 365
Mill Close Mine, England, 855
ore bodies, 658
Ruby Gulch gold mines, Montana, 205
Sediments, radioactivity (abstract), 941
Segaud, —., on pitchblende, 24

Seismology and seismic prospecting (review), 463
Serpentine, 542
Serpentines, Wyoming, 815
Seyler, C. A., on vitrain, 485
Shades and screens for isometric block diagrams (Ives), 419
Sharpstone, D. C., abstract of paper by, 127
Shead, A. C., on hematite, 282
Short, M. N., on textures, 408, 417
Sienna ("ocher") deposits of the Cartersville district, Georgia (Kesler), 324
Sierra Leone, mineral resources (discussion), 460
Silica, 697, 928
Silica minerals, Columbia River valley (review), 932
Silicification, 500
Silver, 882
  Alaska, Chichagof district (abstract), 126
  Arbus district, Sardinia, 91
  Bonanza King mine, Nev., 106
  Childs-Aldwinkle mine, Arizona (review), 347
  cinnabar and gold-silver deposits (abstract), 468
  Colorado, Leadville ores, paragenesis (abstract), 135
    San Juan district, mineral sequence (abstract), 129
  Day Dawn mine, New Guinea, 173
  Kolar, Porcupine, and Kirkland Lake, 647
  Mammoth district, Arizona (review), 347
  Montana, Ruby Gulch gold district, 201
  New Guinea, Wau-Edie Creek area, 890
  New Mexico, Lordsburg district (review), 731
  Quebec, Montauban zone, 712
  Ropes mine, Mich. (abstract), 939
  Tombstone, Ariz., 790
Silver ore type, The nickel-cobalt-native (Bastin), 1
Silver-pitchblende deposit at Contact Lake, Great Bear Lake area, Canada (Furnival), 739
Simpson, E. S., on metasomatism, 783
Singewald, J. T., Jr., on ilmenite, 280
  on veins, 48
Singewald, Q. D., abstract of paper by, 132
Skerl, A. C., on granite, 252
Slates of east Tennessee (Amick), 451
Smeeth, W. F., on Kolar district, Mysore, 648
Smith, G. O., on asbestos, 828
Smith, J. P., on limestone, 101
Smith, W. D., on intrusives, 302
Smyth, C. H., Jr., on oolites, 284
Soapstone, Quebec, Thetford district (review), 236
Soboleff, N. D., on chrysotile, 837
Sobolev, V., on magnetite, 926
Society of Economic Geologists, 125, 355, 467, 938, 939
Soils, Texas, Lynn and Lubbock Counties (discussion), 459
Solutions on minerals at elevated temperatures, Action of alkali sulphide (Lindner and Gruner), 537
Somerlad, H., on copper, 54
Source book in geology (review), 847
South Dakota, pegmatites, Keystone area (abstract), 943
Specularite, 334
Spence, H. S., on bismuth, 21
Spencer, A. C., on covellite, 111
  on serpentine, 816
Sphalerite, 336, 760, 882, 945
  minor elements in (abstract), 136
Spiroff, K., discussion of paper by, 342
Spot tests (review), 464
Spring in west-central Utah, Manganese in a thermal (Callaghan and Thomas), 905
Springs, Nevada, Steamboat Springs (abstract), 471
Sprunk, G. C., on coal, 379, 387
Spurr, J. E., *Diaschistic dikes and ore deposits*, 41–48
  on alaskite, 252
  on faults, 208
  on replacement, 868
Staats, F., on manganese, 919
Stach, E., on clarain, 489
Stadnichenko, T., on coal, 384
Stansfield, A., on titaniferous ores, 280
Stauffer, C. R., review of book by, 582
Stearns, H. T., on springs, 907
Stearns, N. D., on springs, 907
Step, J., on pitchblende, 22
Stephens, M. N., on chalcocite, 416
Stevens, R. E., on solutions, 537
Stibnite, 58, 472
Stilbite, 928
Stillwell, F. L., on metasomatism, 783
Stoiber, R. E., abstract of paper by, 136
Stokes, A. H., on lead, 852
Stokes, H. N., on pyrite, 539
Stopes, M. C., on coal, 476

Stose, G. W., review of bulletin by, 239
Strahan, A., on lead, 852
Strategic minerals (review), 845
Stratigraphy, Anthracite-Crested Butte Quadrangles, Colorado, 370
Bonanza King mine area, Nev., 98
Contact Lake, N. W. T., 742
Franklin County, Alabama, 574
lexicon for Africa (review), 237
Mill Close Mine, England, 856
Quebec, Canadian Malartic Gold mine, 496
Stromeyerite, 761
Structural control of mineralization (abstract), 471
Structural relations of some gold deposits between Lake Nipigon and Long Lake, Ontario (Bruce), 357
Structure, Anthracite-Crested Butte Quadrangles, Colorado, 372
Bonanza King mine area, Nev., 104
Canadian Malartic Gold Mine, 506
Cartersville district, Georgia, 330
chromite deposits (abstract), 130
Chuquicamata, Chile, 677
Contact Lake veins, N. W. T., 746
European lead-zinc deposits (abstract), 944
Kolar, Porcupine, and Kirkland Lake gold fields, 634
Lupa gold field, Tanganyika, 253
Magnolia district, Colo., 440
Mill Close Mine area, England, 862
Ruby Gulch gold district, Montana, 208
Tombstone, Ariz., 791
Structure to petroleum production in eastern Venezuela, The relationship of (Miller), 524
Stuckey, J. L., on barite, 198
Stuckey, L. C., on lead, 852
Sudduth, H., analyses by, 277, 283
Sulphide compounds of copper with arsenic, antimony, and bismuth, The pyrosynthesis, microscope study and iridescent filming of (Gaudin and Dicke), 49, 214
Sulphide solutions on minerals at elevated temperatures, Action of alkali (Lindner and Gruner), 537
Sulphides, Chuquicamata, Chile, 703
Svendsen, R. H., abstract of paper by, 137
Sweetwater, Tennessee, barite deposits, Origin of the (Laurence), 190

Tables —
alkali sulphide solutions, 545
Tables—*Continued*
analyses, chromite, Wyo., 831
copper sulphide compounds, 64, 215
gold ore assays, Day Dawn mine, New Guinea, 176
Grenville rocks, Quebec, 715
limestone, Mill Close Mine, England, 881
magnetite, 926
Wichita Mountains, Oklahoma, 277
manganese, Utah, 915
pitchblende, Contact Lake, N. W. T., 754
rocks, Arbus district, Sardinia, 86
Chuquicamata rocks, Chile, 682
waters, Abraham Hot Springs, Utah, 910
asbestos, optical properties, 826
corrections for block diagrams, 564
diabase alteration to aplite, 34
gold output, Canada and India, 623
industrial chemicals, 288
methyl methacrylate properties, 804
mineral sequence, Adirondack magnetite deposits, 164
nickel-cobalt-silver minerals, 3
ore production, Mill Close Mine, England, 856
stratigraphy, Contact Lake, N. W. T., 742
Mill Close Mine, England, 858
Taff, J. A., on Wichita Mtns., Okla., 269
Talmage, S. B., on hardness tester, 750
Talvitie, N. A., analyses by, 910
Tanganyika, gold, Lupa gold field, 243; (abstract), 128
Tanner, W. F., communication by, 459
Tarr, W. A., on barite, 199
Tatarinoff, M. V., on chrysotile, 837
Taylor, A. V., on Porcelain Rock, 700
Taylor, C. H., on Wichita Mtns., Okla., 269
Teale, E. O., on mineralization, Tanganyika, 265
Teas, L. P., on chalcopyrite, 106
Technique, polishing mineragraphic specimens (abstract), 467
Telain, 485
Telluride-tungsten mineralization of the Magnolia mining district, Colorado (Wilkerson), 437
Tennantite, 69, 708
Tennessee, barite deposits, Origin of the (Laurence), 190
Slates of east (Amick), 451

Terrestrial magnetism (review), 934
Tertiary mineralization in New Guinea, Metasomatism associated with (Fisher), 890
Tetrahedrite, 58, 106, 708, 753
Texas, mercury, Terlingua region (abstract), 125
soils, Lynn and Lubbock Counties (discussion), 459
Textbook of geomorphology (review), 734
Textures, bornite-chalcocite microtextures, 400; (abstract), 135
Thermal spring in west-central Utah, Manganese in a (Callaghan and Thomas), 905
Thiel, G. A., review of book by, 582
Thiessen, R., on coal, 379, 387, 476
Thomas, H. E., with Callaghan, E., *Manganese in a thermal spring in west-central Utah,* 905–921
abstract of paper by, 130
Thompson, E., on galena, 760
Tickell, F. G., review of book by, 352
Tilley, C. E., on cordierite, 725
Titanite, 156
Toadstone, 859
Todd, E. W., on carbonates, 640
Tolman, C., abstract of paper by, 946
Tolman, C. F., Jr., on chalcocite, 407
on mineralizers, 46
Tourmaline, 107, 256
Touwaide, M. E., on bornite, 408
Traill, J. G., *The geology and development of Mill Close Mine, Derbyshire,* 851–889
abstract of paper by, 134
Tremolite, 718
Truscott, S. J., on valuation, 592
Tungsten, Colorado, Boulder County (abstract), 132
ferberite and gold tellurides (abstract), 939
Tungsten mineralization of the Magnolia mining district, Colorado, Telluride- (Wilkerson), 437
Tunnels, California, Claremont tunnel (abstract), 469
Tuomey, M., on limestone, 573
Turner, H. G., on anthracites, 384

Underground water, flow (abstract), 946
Iowa, Dakota sandstone (abstract), 940
Oklahoma, Panhandle (abstract), 942
salt water intrusion in coastal regions (abstract), 129
Union South Africa, cobalt, Balmoral, 17
U. S. S. R., copper, red bed deposits, Urals (discussion), 114
United States, geologic names (review), 122
Ussher, W. A. E., on Cornwall district, 12
Utah, Manganese in a thermal spring in west-central (Callaghan and Thomas), 905; (abstract), 130

Valuation and examination of mines (review), 462
Valuation of mines, Geological factors in the (McLaughlin), 589
Vanadium, Mammoth district, Arizona (review), 347
Van Aubel, R., on chalcocite, 413
Vanderwilt, J. W., review of paper by, 347
Van Hise, C. R., on iron, 602
Van Orstrand, C. E., on geothermal gradients, 376
Varvill, W. W., on lead, 852
Veins, Adirondack magnetite deposits, 162
Arbus lead-zinc district, Sardinia, 88
Bonanza King mine, Nev., 104
Contact Lake area, N. W. T., 744
Cripple Creek, Colo. (abstract), 947
Day Dawn gold mine, New Guinea, 178
dike and vein relationships, 41
dislocated inclusions (discussion), 727
Hog Mtn., Ala., and Paracale, Philippines, 310
inclusions, Grass Valley, Calif. (discussion), 343
Lordsburg district, N. M. (review), 732
Lupa gold field, Tanganyika, 254
molybdenite, Questa, New Mexico (review), 347
Nipigon and Long Lakes region, Ontario, 358
Sweetwater barite deposits, Tennessee, 192
tungsten veins, Boulder Co., Colorado (abstract), 132
Veins in Triassic lavas of Nova Scotia, Magnetite and hematite (Fisher), 921
Venezuela, The relationship of structure to petroleum production in eastern (Miller), 524
Verloop, J. H., on veins, 16
Virginia, barite, 198

Vitrain, 478
Vogt, J. H. L., on bismuth, 21
Voit, F. W., on Dobschau ore deposits, Hungary, 15
von Eckerman, H., on magnesia, 721
von Huene, R., abstract of paper by, 467

Wagner, P. A., on platinum, 610
Wagoner, L., on silver, 32
Waldemar Lindgren (Graton), 850a
Walker, H. A., on mapping, 888
Wall, E. J., on reducer, 421
Waring, G. A., on springs, 907
Warren, H. V., abstract of paper by, 128
Washington, manganese, Olympic Peninsula (abstract), 944
  mineral utilization (review), 932
Waters, Abraham Hot Springs, Utah, 909
  Mill Close Mine, England, 885
Weathering, Cartersville district, Georgia, 337
Wedd, C. B., on fluorspar, 852
  on lead, 852
Weed, W. H., on gneiss, 202
  on tinguaite, 207
Wells, A. K., review of book by, 121
Western Australia, metasomatism near gold deposits, 781
Whitaker, J. R., review of book edited by, 734
White, C. H., abstract of paper by, 945
White, D. E., abstract of paper by, 133
Whitehead, W. L., abstract of paper by, 941
  on silver, 27
  on textures, 405
Wichita Mountains, Oklahoma, The iron ores of the (Merritt), 268
Wiebenga, W. A., discussion by, 343
Wilkerson, A. S., *Telluride-tungsten mineralization of the Magnolia mining district, Colorado*, 437–450
Willems, H. W. V., on iron, 169
Williams, A. J., on hematite, 282
Willis, B., on Mbeya Mtn., Tanganyika, 243
Wilmarth, M. G., review of bulletin by, 122
Wilson, B. H., review of book by, 352
Wilson, E. D., on manganese, 791
Wilson, H., on mineral pigments, 325
Wilson, M. E., on cordierite, 725
Winchell, A. N., on oxymagnetite, 155
Wisser, E., *Geologic parallels: Hog Mountain, Alabama, and Paracale, Philippine Islands*, 297–323
  abstracts of papers by, 127, 468
  on fractures, 313
  on outcrops, 670
Wittichenite, 223
Witwatersrand gold field, 607
Worcester, P. G., review of book by, 734
Wright, C. W., *The lead-zinc ore deposits and geology of the Arbus area in Sardinia, Italy*, 82–95
Wulfenite, 350
Wyoming, Asbestos and chromite deposits of (Beckwith), 812

Young, A. C., on gold, 623

Zeigler, V., on bismuth, 21
Zinc, Alabama, galena-sphalerite deposit (abstract), 945
  England, Mill Close Mine, 851; (abstract), 134
  European deposits (abstract), 944
  Montauban zone, Quebec, 712
  New Mexico, 655
  sphalerite, minor elements in (abstract), 136
  Tennessee deposits, 197
  Tombtone, Ariz., 790
Zinc ore deposits and geology of the Arbus area in Sardinia, Italy, The lead (Wright), 82
Zoning, barite deposit, Sweetwater, Tennessee, 196
  Chuquicamata, Chile, 710
Zwierzycki, J., on coal, 385

ECONOMIC GEOLOGY

VOL. XXXIV JANUARY–FEBRUARY, 1939 No. 1

THE NICKEL–COBALT–NATIVE SILVER ORE TYPE.[1]

EDSON S. BASTIN.

ABSTRACT.

Salient characters of the nickel-cobalt-native silver ore type as displayed in many parts of the world are reviewed. A primary origin for most of the native silver is indicated but downward enrichment appears to have developed rich ores in a few localities. In most districts where evidence of genetic relationship between ore deposition and igneous intrusion is available a derivation of the mineralizing solutions from acid magmas, mostly granitic, is indicated. The Ontario deposits are anomalous in forming an apparent exception to this rule as these deposits are associated with diabase sills. Evidence is presented indicating (*a*) that the causes of this association may be largely structural, and (*b*) that at Bruce Mines, Ontario, granite dikes cut the diabase flows and are in turn cut by the veins. It is concluded on this and other grounds that the mineralizing solutions in the Ontario districts may well have come from granitic rather than diabasic magmas.

THE ORE TYPE DEFINED.

THE ore type under consideration is not of common occurrence. Its representatives are, however, widely scattered over the world and are not restricted to a few metallogenic provinces. In spite of such scattered distribution they show a remarkable similarity in the kinds of minerals developed even though the proportions are highly variable. This similarity in widely separated occurrences implies that these ores were not the product of unusual local

[1] Representing, with revisions and additions, a presidential address delivered before the Society of Economic Geologists Chicago meeting, December 28, 1933.

combinations of conditions but occupy a definite and ordered place in the broad scheme of ore genesis.

Many of the best examples of the type are no longer exploited. The old descriptions were written before the modern concepts of the relations of ore deposition to vulcanism had developed and before the birth of the concept of downward enrichment, and the descriptions are often colored by the theories of ore genesis in fashion at the time, especially that of lateral secretion.

Table I lists the minerals that have been reported from all of the nickel-cobalt-silver deposits about which sufficient data are available and there is included also the group of deposits similar in other respects but poor in silver. R—indicates that the mineral is rare. Only those minerals are included that are certainly or possibly primary. Products of oxidation are omitted as not pertinent to this study.

The metallographic microscope has revealed that some of the nickel and cobalt minerals of these deposits formerly believed to be simple are in reality mixtures. Some of the older determinations are therefore inaccurate but not sufficiently so to materially effect general conclusions concerning genesis.

Microscopic methods of study of polished specimens were applied first to the study of the later developments in Canada and to one deposit in the United States but have recently been extended to the ores of the Erzgebirge. Although the minerals present are listed, the descriptions contain little regarding their relative abundance; only recently has Ellis Thomson made quantitative studies on some of the Canadian ores.

The minerals that in particular give character to these ores are the arsenides and sulpharsenides, antimonides and sulphantimonides of nickel and cobalt and the districts tabulated were chosen on the basis of their presence in moderate or considerable abundance. It is evident from the table that the deposits so assembled also possess other common traits.

Copper is invariably present as primary chalcopyrite and is commonly also present as gray copper, bornite or chalcocite. The gray copper is probably in all cases primary. Bornite is primary

TABLE I.

TABLE I.

Elements, etc.	Johannngeorgenstadt, Germany.	Joachimsthal, Germany.	Annaberg, Germany.	Schneeberg, Germany.	Marienberg, Germany.	Freiberg, Germany.	Wittichen, Germany.	Mansfeld, Germany.	Bieber, Germany.	Kamsdorf, Germany.	Schweina, Germany.	Nanzenbach, Germany.	Nieder-Ramstadt, Germany.	Schladming, Germany.	Nöckelberg, Germany.	Dobschau, Hungary.	Einfischal, Switzerland.	Turtmannstal, Switzerland.	Chalanches, France.	Rin Plaun Is. Castanglas, Sardinia.	Sarrabus, Sardinia.	Cobalt, Ontario.	So. Lorraine, Ontario	Gowganda, Ontario.	Tyrrel-Knight Area. Ontario.	Shininguree, Ontario.	Silver Islet, Ontario.	Great Bear Lake, N. W. T. Canada.	Bullard's Peak, New Mexico, U. S. A.	Wickenberg, Arizona, U. S. A.	Balmoral, So. Africa.	Batopilas, Mexico.	Sabinal, Mexico.
Alemontite	×																		×			×					~						
Amalgam																																	
Antimony																																	
Arsenic		×		×		×				×	×			×					×						×								
Bismuth			×		×		×		×										×														
Gold																			×														
Mercury													×	×					×														
Silver	×	×	×	×	×	×	×						×						×		×	×	×	×	×	×	×	×					
Sulphides																																	
Argentite	×	×	×	×	×	×							×						×		×												
Berthierite									×																								
Bismuthinite		×	×	×		×	×					×					×																
Bornite							×	×			×		×			×																	
Boulangerite								×																									
Chalcocite		×								×					×																		
Chalcopyrite	×	×		×			×		×																								

TABLE I.—*Continued*

| | | |

TABLE 1.—*Continued*

	Johannegeorgenstadt, Germany.	Joachimsthal, Germany.	Annaberg, Germany.	Schneeberg, Germany.	Marienberg, Germany.	Freiberg, Germany.	Wittichen, Germany.	Mansfeld, Germany.	Bieber, Germany.	Kamsdorf, Germany.	Schweina, Germany.	Nanzenbach, Germany.	Nieder-Ramstadt, Germany.	Schladming, Germany.	Nöckelberg, Germany.	Dobschau, Hungary.	Einfischal, Switzerland.	Turtmannstal, Switzerland.	Chalanches, France.	Rin Plaun Is. Castangias, Sardinia.	Sarrabus, Sardinia.	Cobalt, Ontario.	So. Lorraine, Ontario	Gowganda, Ontario.	Tyrrel-Knight Area, Ontario.	Shiningtree, Ontario.	Silver Islet, Ontario.	Great Bear Lake, N. W. T. Canada.	Bullard's Peak, New Mexico, U. S. A.	Wickenberg, Arizona, U. S. A.	Balmoral, So. Africa.	Batopilas, Mexico.	Sahinal, Mexico.
ANTIMONIDES AND SULPH-ANTIMONIDES																																	
Breithauptite																																	
Dyscrasite																																	
Ullmannite																																	
SULPHO-SALTS																																	
Bournonite																																	
Emplectite																																	
Enargite																																	
Epigenite																																	
Jamesonite																																	
Klaprothite																																	
Matildite																																	
Polybasite																																	
Proustite																																	
Pyrargyrite																																	
Pyrostilpnite																																	
Rittingerite																																	
Stephanite																																	
Smaltite																																	

TABLE I.—*Continued*

| | | |

as at Cobalt and neighboring Canadian camps. Chalcocite is known to be secondary in some of the deposits and has not been definitely shown to be primary in any of them, though that possibility must be admitted. Copper minerals are sufficiently abundant in some cases to be of commercial importance as at Schwartleo, Dobschau and Cornwall.

Bismuth as the native metal and as the sulphide bismuthinite is present in most of the deposits. Rarely, other primary bismuth minerals occur.

Silver is present in nearly all the deposits mainly native and as argentite but subordinately as the sulphosalts—notably the ruby silvers—and in other forms.

Lead is present in nearly all the deposits as galena and in a few as jamesonite and cosalite but is generally a minor component. Zinc is present as sphalerite in a considerable proportion of the deposits but always in small amounts.

Iron is represented among the metallic minerals principally by pyrite present in all deposits, by arsenopyrite in nearly all, by the arsenide löllingite in a few, and rarely by pyrrhotite. Marcasite is reported from about half the occurrences.

Among the minor metallic components, the presence of the uranium mineral pitchblende in the ores of the Erzgebirge, Cornwall and Great Bear Lake is particularly noteworthy. Mercury as cinnabar, the element or amalgam, is reported in small amounts from a few deposits but without details as to its relations to the dominant ore minerals. The metal is certainly not characteristic of the type. The general absence of gold is noteworthy, though small amounts occurred in the gossans at Chalanches, France.

Among the gangue minerals quartz is almost invariably present but forms the principal gangue only in a few occurrences. In some instances, as at Schneeberg, the quartz is a late pseudomorphic replacement of other gangues. In general, carbonates are the dominant gangue—ranging from calcite and dolomite to ankerite and siderite. Barite is present in about half the occurrences and fluorite in a few.

TYPE OCCURRENCES.

Excellent summary descriptions of the principal occurrences complete to 1905 are available in "Die Erzlagerstätten" of Stelzner-Bergeat and Keil [2] has presented more recent summaries for some areas. It is appropriate here only to sketch roughly the geology of the more significant areas, stressing those features that throw light on the genesis of the ores.

The Erzgebirge of Germany and Czechoslvakia.

The range of low mountains forming for about eighty miles the boundary between Saxony and Bohemia has better claims than any other region to be considered the birthplace of the science of ore deposits. There, in the sixteenth century, at Joachimsthal lived Agricola, the great master of his day on the occurrence, mining and treatment of ores. There Werner developed his famous neptunist concepts of the origin of ore deposits and of rocks. There also at Freiberg lived and taught Breithaupt and Von Cotta, Stelzner and Beck. There were fought out many of the theories of ore genesis from the neptunist ideas of Werner to the theory of lateral secretion.

An excellent summary of the geology of the western part of the Erzgebirge has been given by Dalmer.[3]

In the western Erzgebirge the main mass of the mountains is composed of Archaeozoic schist formations—the mica schist and the phyllites—while gneisses occur farther east. On the phyllites and forming the northern flank of the range lies a broad zone of much disturbed Paleozoic formations, from Cambrian to Lower Carboniferous in age, which in turn are overlain unconformably by gently dipping Upper Carboniferous and Permian beds. The Archaeozoic formations owe their attitude in the main to mountain-making movements in Carboniferous times.

Probably in Upper Carboniferous times the Archeozoic rocks of the western Erzgebirge were invaded by a number of granite

[2] Keil, Karl: Beiträge zur Kenntniss der Co, Ni, Bi, Ag veins. Jahrb. Berg und Huttenweise, Sachen., 105: 95–132, 1931.

[3] Dalmer, Karl: Die Westerzgebirgische Granit-massivzone. Zeitsch. f. Prak. Geol., pp. 297–313, 1900.

masses, the largest of which is the great Neudeck-Eibenstock massif. The westernmost of these masses penetrates the Cambrian at its northern end. The granites are not uniform in composition and dikes of lithium granite cut biotite granite. The age differences, however, are considered to be slight. Dikes of quartz porphyry and granite porphyry, analogous to the Elvan of Cornwall, cut the schists and less commonly the granites. Much less abundant are dikes of more basic composition—diorites, minettes and kersantites. Both classes of dikes, because of their spacial relations to the granites and because they are cut by the tin veins, are believed to be after effects of the granite intrusions. Dikes of basalt and phonolite cut the veins of all types and are believed to be Tertiary.

The granite masses are surrounded by contact metamorphic aureoles in the schists. Many schist masses clearly form only a thin capping over granite. Mineralization is believed to be roughly coextensive with the sub-surface distribution of the granite but the surface distribution of the ores is uneven, and is localized in three northwest striking zones separated by ore-poor areas. In the westernmost of these areas lie the mining camps of Schneeberg and Johanngeorgenstadt, Zwittermühl and Joachimsthal. In the middle area are Geyer, Ehrenfriedersdorf and Annaberg and in the eastern area Marienberg.

In all three mineralized zones there is a uniform age sequence as follows:

(*a*) Tin ores,
(*b*) Pyritic lead ores,
(*c*) Cobalt-silver ores,
(*d*) Iron-manganese ores.

Throughout all the districts the cobalt-silver ores are the most important.

In general the tin veins occur mainly in and close to the granites and especially in schist roof-pendants. The other vein types are more remote from the granite contacts. The pyritic lead ores, especially at Annaberg, show transitions to the tin veins and have

been regarded by nearly all observers as closely related to them in age and in origin.

The cobalt-silver veins and the iron-manganese veins, which in places seem to grade into one another, are clearly younger than the tin and pyritic-lead veins, which they in many places transect. Opinions have differed, however, as to whether this age difference is large or small. Herrmann Müller and other early writers believed that they were as young as Tertiary partly because of the rare occurrence of small amounts of native silver and ruby silver in cracks in the Tertiary basalt dikes. The basalt dikes, however, transect the veins of all types and in places enclose fragments of them. The rare occurrences of silver minerals in the dikes are probably secondary depositions from meteoric waters or possibly rearrangements of older minerals by waters accompanying the basalt intrusions. Moreover, Dalmer has shown that pebbles of the iron-manganese ores occur not only in Oligocene but in Upper Cretaceous conglomerates.[4] The younger veins are therefore older than Upper Cretaceous and most of the later writers follow Dalmer in his conclusion that, "The intimate association of the older and the younger vein formations into ore zones that in places stand in striking relationship to the granite masses indicates that they do not represent two completely independent episodes of ore deposition but rather two sequential acts in the same geologic drama; and further that the younger veins as well as the older stand in some sort of relation to the granite intrusions."

Schumacher has reached similar conclusions in regard to neighboring Freiberg districts where cobalt-nickel ores occur in less abundance. All the vein formations are derivatives of a single cryptobatholithic granite magma whose advancing differentiation is expressed in the different mineralogic character of the vein formation. A Tertiary so-called basaltic mineralization does not exist.[5]

[4] Dalmer, Karl: Neber das Alter der jüngeren Gangformationen des Erzgebirges. Zeitsch. fur prak. Geol., pp. 1–6, 1896.

[5] Schumacher, Friedrich: The genesis of the Freiberg ore district. XVI. Int. Geol. Cong. Rept., I: 399–405, 1933.

Cornwall.

The striking analogies of the Cornwall district to the western Erzgebirge are well known. In that region sedimentary formations with minor associations of igneous rocks, ranging in age from probable Cambrian to Lower Carboniferous, were intruded in late or post-Carboniferous times by five granitic stocks with which most of the mineral wealth of Britain is associated.[6]

In places cutting the granite but more commonly the bordering formations are the Elvan or dikes of granite porphyry, quartz-porphyry, microgranite and aplite whose petrologic relations to the granite are so obvious that there can be little doubt that they are late phases of the granitic intrusions. Much less abundant than the granitic dikes are the minette dikes that occur farther from the granite masses. These rocks carry orthoclase and biotite as their principal components with quartz, apatite and carbonates as the principal accessories and they not uncommonly carry inclusions of quartz, feldspar and pegmatite—some rounded and some angular.[7] Augite has been rarely detected in them. With respect to the age of these more basic dikes there is some uncertainty and difference of opinion, but their abundant orthoclase and accessory quartz would accord with the view that they are differentiates from the deeper portions of the granite masses.

In addition to the dominant tin-copper group of veins, whose genetic relation to the granite is generally accepted, there occur younger veins whose genesis is less certain. They are not found in the granite and commonly occur at some distance from it. These include (1) silver-lead ores occasionally carrying cobalt and nickel minerals and (2) iron-manganese veins, and thus present analogies to the younger vein types of the Erzgebirge. The silver-lead ores are characterized by rich silver minerals, galena, sphalerite, pyrite, arsenopyrite, chalcopyrite, carbonates and in places by cobalt and nickel minerals, bismuth, bismuthinite

[6] MacAlister, D. A.: Geological aspects of the lodes of Cornwall. Econ. Geol., III: 363–380, 1908.

[7] Hill, J. B., and MacAlister, D. A.: Geology of Falmouth and Truro and the mining district of Camborne and Redruth. Mem. Geol. Surv. England and Wales, 1906.

and rarely pitchblende.[8] In places these veins cut the tin-copper veins but generally they occur outside the areas of tin mineralization. In a few instances minerals characteristic of these veins, including those of nickel and cobalt, are found within the tin-copper veins, as at the famous Dolcath mine.

According to Ussher, Barrow and MacAlister[9] "These lodes are probably of different ages, but their association with the mineral district as a whole makes it probable that they were genetically connected with the eruptive after-actions following the intrusion of the granite and elvans."

Canada.

The mineralogical similarity of the cobalt-silver veins of Ontario, Canada to those of Europe is apparent from Table 1. Bismuth and more rarely bismuthinite is consistently present. Pitchblende, however, is absent. The deposits occur interruptedly from Elk Lake on the north to South Lorraine on the south—a distance of around sixty miles, and from the Ontario-Quebec boundary on the east to Shining Tree—a span of about seventy miles. Minor occurrences have been noted as far southwest as the Bruce Mines area on the north shore of Lake Huron.

Unlike those of many of the European districts the cobalt-silver ores of Ontario occur alone and not as part of a sequence of vein types. Copper minerals are present however, though seldom in workable amounts. The deposits invariably occur in or near prevailingly sill-like intrusions of quartz diabase. These sills are localized mainly at or near the great unconformable contact between the nearly horizontal Upper Huronian Cobalt formation and the surface of older rocks on which it was deposited. These older rocks, though varying widely in age and origin, have, nevertheless, one important characteristic in common—namely, the absence of horizontal structures. Intrusives invading them would be likely, therefore, to assume the forms of dikes or stocks

[8] Hill, J. B., and MacAlister, D. A.: Idem.

[9] Ussher, W. A. E., Barrow, G., and MacAlister, D. A.: Geology of the country around Bodmin and St. Austell. Mem. Geol. Surv. England and Wales, 1909.

and would only spread laterally in sill-like form upon reaching the flat-lying sediments of the Cobalt Series.

The veins generally follow steeply inclined fractures occurring particularly in the Cobalt Series, less commonly in the Nipissing diabase sills and still less commonly in the older (mostly Keewatin) rocks. Something like eighty per cent of the production has come from veins in the Cobalt Series. Although most of the veins follow steeply inclined fractures of small displacement, a few occur along faults of gentler dip and of larger displacement ranging in instances that have been measured from 30 to 75 and even 550 feet (Cobalt Lake fault). It is noteworthy that in the Cobalt and South Lorraine areas the larger faults are thrust faults [10] and that many of them dip to the southeast. It is evident that after the intrusion and complete solidification of the diabase sills, faulting under regional compressive stresses took place and was followed—how promptly is uncertain—by mineralization.

As already indicated, veins are less common in the Nipissing diabase than in the bordering rocks and when present are in its upper or lower portions rather than its central part. In Cobalt—the most productive camp—more than ninety per cent of the production has come from veins a short distance below the diabase sill but large areas of the upper contact have of course been removed by erosion. At the less important camps of South Lorraine and Gowganda the veins are in or above the tops of the sills.

The view that the cobalt-silver veins near Cobalt were deposited by solutions originating in the Nipissing diabase was early adopted and gained strength from each new discovery in outlying camps where similar associations of the ores with diabase were found. It finds strong support in the unfailing association of the ores with diabase and the absence of any large bodies of igneous rocks known to be younger than the diabase.

Of especial significance in their bearing on the nature and source of the mineralizing solutions are the pink aplites or granophyres found mainly in the Elk Lake and Gowganda districts and

[10] Knight, C. W.: Cobalt and south Lorraine silver areas. Ontario Dept. Mines, 31st Ann. Rept.: 12–17, 1924.

a single dike-like mass of soda granite cutting the Nipissing diabase in the University mine at Cobalt. The aplites of the Elk Lake and Gowganda districts occur as occasional narrow dike- or vein-like masses whose width varies from a mere seam to a foot or two and whose length seldom exceeds a few hundred feet. Bodies of this shape have thus far been found only in the Nipissing diabase. Some of the more productive silver veins of Gowganda like those of the Miller Lake-O'Brien mine are not associated with aplite but where aplite occurs in dike-like forms its association with the mineralization is so intimate that the aplite must be regarded not merely as paralleling the mineral vein but as constituting an integral part of it. To quote Burrows:[11] "Some veins show aplite next to the diabase, followed by a layer of crystallized quartz, the crystals of which extend into the calcite which may occupy the center of the vein. This type of vein frequently carries some native silver, smaltite and niccolite. . . . The aplite type of vein, however, varies greatly in the arrangement of the constituent parts, the calcite and ores often being irregularly distributed in the aplite."

The aplites have been described particularly by Barlow,[12] Collins,[13] Hore[14] and Bowen[15] and their importance as bearing on ore genesis has been recognized by all these writers. The microscope shows the prevailingly pink color to be due to acid plagioclase near the albite end of the series and reveals also the presence of quartz, chlorite, calcite, titanite and a little apatite with rarely barite and celestite. Micrographic intergrowths of quartz and feldspar are common. The ore minerals tend to be most abundant near the center of the veins and include chalco-

[11] Burrows, A. G.: Gowganda silver area. Ontario Dept. of Mines, XXX, Pt. III: 21, 1921.

[12] Barrow, A. E.: The origin of the silver of James Township. Jour. Can. Min. Inst., XI: 256–272, 1908.

[13] Collins, W. H.: Geology of Gowganda mining division. Canada Dept. of Mines, Geol. Surv., Mem. 33, 1913.

[14] Hore, R. E.: Differentiation products in quartz diabase masses of the silver fields of Nipissing, Ontario. Econ. Geol., VI: 51–59, 1911.

[15] Bowen, N. L.: Diabase and granophyre of the Gowganda Lake district, Ontario. Jour. of Geol., XVIII: 658–674, 1910.

pyrite, bornite, pyrite, galena, cobalt and nickel arsenides, native silver, argentite and specularite. The mineral composition of the aplite is in marked contrast to the diabase, which is characteristically composed of labradorite, pyroxenes, quartz, biotite, apatite and titaniferous iron ores.

A comparison of analyses [16] of vein-like aplites, selected from those poor in calcite, with analyses of typical Nipissing diabase shows that the aplites are notably richer in silica and soda, poorer in calcium and magnesium, and almost or quite free from potash. The silica content is 58 to 78% as against around 50% in the diabase.

The recently developed silver-pitchblende deposits of Great Bear Lake in northern Canada [17] carry cobalt and nickel minerals and native bismuth and exhibit dendritic and concentric arrangements entirely analogous to those in the ores of the Erzgebirge and in Cobalt and neighboring camps. The deposits thus far examined occur in folded pre-Cambrian sediments and volcanics, commonly within a mile of their contact with intrusive granite. Basic dikes and sills cut sediments, volcanics and the granite, but little mineralization has been found in these basic intrusives. Some of them are quartz-bearing norites. Kidd regards the granite as the probable source of the mineralizing solutions.

Other Districts.

The geologic relations of many deposits of the cobalt-silver type are less suggestive as to the source of the mineralizing solutions.

The deposits of Dobschau in the Carpathians of Hungary [18] occupy fractures in a diorite stock that has intruded Devonian schists. The mineralization is not however genetically connected with the diorite for it has affected Carboniferous sediments that

[16] Hore, *op. cit.*, p. 54.

[17] Kidd, D. F.: A pitchblende-silver deposit in Canada. ECON. GEOL., XXVII: 145–159, 1932. Also Summary Rept. Geol. Surv. Canada, Part C: 1–36, 1932.

[18] Voit, F. W.: Geognostische Schilderung der Lagerstätten Verhaltnisse von Dobschau in Ungar. Jahr. d. K. Koniglichen. Geol. Reichsanstalt., L: 695–727, 1900.

overly the diorite and the Devonian schists. No igneous rocks younger than the diorite occur. The ores, which show no contact or dynamo-metamorphism, carry abundant tourmaline, a feature strongly suggestive of the derivation of the mineralizing solutions from acid or intermediate rather than basic magmas.

At Breto and Castanheiro in Portugal, according to Breithaupt,[19] smaltite occurs with quartz in granite dikes that traverse granites.

The veins near Wittichen in Baden and Württemberg [20] traverse not only older metamorphic and igneous rocks but the overlying Buntsandstein and cannot be correlated with particular types of igneous rocks.

At Nieder-Ramstadt [21] near Darmstadt, Germany, the youngest igneous rocks are mica-poor granites and their pegmatitic and aplitic facies. The single silver-cobalt-nickel vein is younger than these but there is no evidence for or against a genetic relation between the mineralization to the granitic magmas.

Veins of the type under discussion occur near Leogang, Germany,[22] at Schladming in Styria, Germany,[23] at Nanzenbach, Germany,[24] and in the Val d'Anniviers and Turtmanntal in Switzerland [25] but no evidence has been adduced as to the sources of the mineralizing solutions.

Studies of museum specimens from the island of Sardinia show the presence of ores of the type here under discussion at Rin

19 See Stelzner-Bergeat, Die Erzlagerstäten, II: 865, 1905–6.

20 Stelzner-Bergeat, *op. cit.*, pp. 699, 745.

21 Klemm, G.: Über einen Silber, Kupfer und Kobalterze führenden Gang bei Nieder-Ramstadt im Odenwalde. Zeitsch. f. prak. Geol., pp. 41–43, 1923. Ramdohr, Paul: Die Silberkobalterzgang mit Kupfererzen von Nieder-Ramstadt bei Darmstadt. Notizblatt des Vereius für Erdkunde und der Hessischen Geologischen Landes-anstalt zu Darmstadt., pp. 164–192, 1923.

22 Buchrucker, L.: Die Mineralien der Erzlagerstätter von Leogang in Salzburg. Zeitsch. f. Krys. und Min., 19: 113–166, 1891. Redlich, K. A.: Das Bergrevier des Schwartzleotales bei Leogang. Zeitsch. f. prak. Geol., pp. 41–49, 1917.

23 Schmidt, C., und Verloop, J. H.: Notiz über die Lagerstätte von Kobalt und Nickelerzen bei Schladming in Stiermark. Zeitsch. f. prak. Geol., pp. 271–275, 1909.

24 Stelzner-Bergeat, *Op. cit.*, p. 870.

25 Stelzner-Bergeat, *Op. cit.*, pp. 871–872.

Planu is Castaugias.[26] In this region a granitic stock intrudes black metamorphic schists and the vein carrying nickel and cobalt minerals occurs about ½ km. from the granite contact. Other vein types are also present.

In the Sarrabus district of Sardinia[27] Silurian schists are traversed by great batholiths of granite and by intrusions of porphyries and aplites. In the schists and more rarely in the granite occur a series of three veins carrying silver, nickel and cobalt minerals whose genesis according to Piepoli, is probably linked with the emplacement of the granite.

The silver-cobalt-nickel veins of Chalanches,[28] in the Dauphine, France, traverse biotite gneisses and transect dikes of diabase but the source of the mineralization is obscure.

Near Vinchina in Argentina[29] talcose schists are traversed by a vein carrying cobaltite and arsenopyrite in a quartz gangue and rich in both gold and silver. The deposit is near the contact with the acid intrusive that makes up most of the Cerro de Famatina.

At Balmoral in South Africa[30] veins carrying nickeliferous smaltite but poor in silver traverse fine-grained feldspar-augite rocks near their contact with intrusive red granite. Gabbro forms several small hills in the vicinity. The principal minerals of the veins according to Horwood are quartz, light pink feldspars and hornblende while minor components are smaltite, chalcopyrite, and molybdenite—the latter consistently present. The feldspars are orthoclase and plagioclase. Horwood points out the mineralogical similarity between the veins and the neighboring red granite and regards the veins as essentially pegmatitic facies of

[26] Piepoli, M. P.: Etude microscopique de quelques minerais du filon cobalto-nickelifere de Rin Planu is Castaugias. Soc. Francaise de Mineral., Bull., 57: 270–283, 1934.

[27] Piepoli, M. P.: Etude microscopique de quelques minerais des filons argentiferes du Sarrabus. Soc. Francaise de Mineral., Bull., 56: 277–302, 1933.

[28] Ricard, T. A.: The mines of Chalanches, France. A. I. M. E., Trans., XXIV: 689–705, 1894.

[29] Ericksson, O. S.: An Argentine cobalt mine. Eng. and Min. Jour., 78: 176, 1904.

[30] Dorffel, D.: The Balmoral cobalt lodes. Geol. Soc. S. Africa, Trans., VI, Pt. I: 93–94, 1903. Horwood, C. B.: The red granite of Balmoral and its relation to the cobalt lodes. Geol. Soc. S. Africa, Trans., VII: 110–114, 1904.

the granite intrusion. The constant presence of molybdenite is also suggestive of such an origin. The principal mine is only 700 to 800 yards from the granite border and the veins strike toward the granite contact.

In the Sabinal district in Mexico [31] lower Cretaceous sediments, including limestones, are intruded by a large body of alaskite whose principal components are quartz and soda feldspar although orthoclase and muscovite also occur. Dikes of alaskite and of diabase also cut the Cretaceous sediments. Contact metamorphic deposits occur in the Cretaceous limestones next the intrusive and at distances of 50 m. to 1 km. from it occur fissure veins of the nickel-cobalt-silver type some of which have been highly productive. Of the source of the mineralization Krieger says: [32] "The near-by presence of a large intrusive mass, the metallic deposits in the contact zones and the alteration of the wall-rock of the veins by solutions similar in composition to the igneous mass, all point to the alaskite intrusive as the most obvious source of the mineralizing solutions."

In the Batopilas district in Mexico [33] veins of the type under discussion also occur in fissures traversing diorite and andesite. These rocks have been intruded by granite and according to Krieger,[34] "A preliminary study of the geology of the district indicates that the mineralization was probably connected with the granitic intrusives."

Museum specimens from Bullards Peak, New Mexico,[35] indicate the presence of nickel skutterudite and native silver but no field data are available.

The rich silver ores of the Monte Cristo mine, near Wickenburg, Arizona, described by the present writer in 1922 [36] consti-

31 Krieger, Philip: Primary silver mineralization at Sabinal, Chihuahua, Mexico. ECON. GEOL., 30: 242–259, 1935.

32 Idem, p. 259.

33 Krieger, Philip: Primary native silver ores at Batopilas, Mexico and Bullards Peak, New Mexico. Am. Miner., 20: 715–723, 1935.

34 Idem., p. 717.

35 Krieger: Idem, p. 719.

36 Bastin, E. S.: Primary native-silver ores near Wickenburg, Arizona, and their bearing on the genesis of the silver ores of Cobalt, Ontario. U. S. Geol. Surv., Bull. 735: 131–155, 1922.

tute another example of this ore type. The dominant country rock in the vicinity of the mine is a granite gneiss which has been intruded by dikes of granite pegmatite and of fine-grained diabase which commonly parallel the foliation of the gneiss. The mineralization is younger than all these rocks and evidence is lacking as to the source of the mineralizing solutions.

GENETIC RELATIONSHIPS TO SPECIFIC CLASSES OF IGNEOUS ROCKS.

Significance of the Major Components.

In a number of districts, notably at Cornwall, Nanzenbach, Val d' Annivers and Tutmanntal, cobalt-nickel veins of the type under consideration are associated with workable copper deposits and copper minerals—chalcopyrite and commonly bornite—are present in all occurrences of the type. As is well known, however, copper mineralization may be associated with acid, intermediate or basic magmas. The association of cobalt and nickel with copper is of significance therefore only as indicating the possibility of a similarly wide range of genetic relationships for these metals.

The common genetic association of nickel and cobalt with basic rocks is too well known to require elaboration but the ratio in which these metals are present shows variations that are not without genetic significance.

In typical sulphide ores of the magmatic or closely related classes, like those of Sudbury, nickel predominates largely over cobalt. The few available determinations of the cobalt to nickel ratio in Sudbury ores [37] show that it ranges from 1:40 to 1:33. Three analyses of the Sudbury mattes show:

Co, 1 to Ni, 59,
Co, 1 to Ni, 52,
Co, 1 to Ni, 127.

[37] Coleman, A. P.: The nickel industry. Canada Dept. Mines, Mines Branch, p. 108, 1913.

An average sample from Norwegian and Swedish magmatic deposits [38] of nickeliferous pyrrhotite would generally give Co, 1 to Ni, 8–15. In a nickeliferous pyrrhotite ore from Maine described by the present writer [39] the ratio in typical material was Co S, 1 to Ni S, 32. In the unweathered peridotites of New Caledonia [40] where the nickel and cobalt occur in silicate minerals the ratio is Co, 1 to Ni, 20–50. In the cobalt-nickel arsenide ores of the type under consideration very different ratios appear to obtain. Sampling of 366 carload lots and 52 smaller lots of ore from Cobalt, Ontario,[41] gave a ratio of about Co, 1 to Ni, 0.6. At Dobschau, Hungary,[42] the average of 18 analyses showed a ratio of Co, 1 to Ni, 2.7. In the ores richest in nickel the ratio is about Co, 1 to Ni, 5.5.

It is evident that the ratio of cobalt to nickel is much greater in the ore type under discussion than in those nickel ores that are unequivocally related in genesis to basic igneous rocks.

Significance of Certain Minor Components.

The presence of bismuth as the native metal or as the sulphide bismuthinite is an almost invariable characteristic of the ore type under consideration. It may be appropriately considered whether its other modes of occurrence give it any genetic significance here.

Bismuth seems *not* to be a characteristic associate of the magmatic type of nickel ores associated with basic igneous rocks. In six analyses of Sudbury mattes no bismuth is reported.[43] According to Vogt,[44] in the matte formed when the Scandinavian nickeliferous pyrrhotite ores are smelted it is usually the case that not even traces of bismuth or of arsenic or antimony can be detected. Bismuth minerals have not been reported from the

38 Beyschlag, Vogt, and Krusch (English translation): Ore Deposits, Vol. I, p 283.

39 Bastin, E. S.: A pyrrhotitic peridotite from Knox County, Maine. Jour. Geol., XVI: 134, 1908.

40 Beyschlag, Vogt, and Krusch: Idem, pp. 953–954.

41 Ledoux, A. R.: Jour. Can. Min. Inst., 10: 62–68, 1907.

42 Voit, F. W.: *Op. cit.*, p. 721.

43 Coleman, A. P.: *Op. cit.*, p. 108.

44 Beyschlag, Vogt, and Krusch: *Op. cit.*, p. 283.

coarse apatite-phlogopite dikes of Norway [45] or Canada [46] that stand in genetic association with gabbros and pyroxenites, or from the alkali pegmatites of Norway.[47]

On the other hand, the common occurrence of bismuth and bismuthinite in granite pegmatites is well established, as for example those of the Black Hills [48] of South Dakota.

The abundant association of bismuth and bismuthinite as primary minerals in the tin and silver-tin veins of Bolivia, which stand in genetic relationship to quartz monzonite intrusives, is well known and these deposits have until recently constituted one of the world's principal sources of bismuth. In the ordinary tin veins that are after effects of granitic intrusions bismuth and bismuthinite are widespread and characteristic minerals. In Altenberg in Saxony, for example, bismuth has been one of the principal products of the mines. Bismuth is a component of the tin deposits in granite in Queensland, Australia, and of the tin veins of Cornwall.

Bismuth and some bismuthinite are also found with gold and molybdenite in quartz veins in the New England district in New South Wales in a contact zone between schists and granite.

Bismuthinite and the bismuth telluride-tetradymite occur at Rezbanya in Hungary [49] in limestones that have been contact metamorphosed by acid and intermediate intrusives.

In the Granite District in Utah [50] bismuthinite occurred in workable amounts in a six foot bed of contact metamorphosed limestones bordering granite.

The copper deposits of Telemarken in Norway [51] carry bismuth, bismuthinite and the bismuth telluride-tetradymite, as well as tin

45 Vogt, J. H. L.: Zeitsch. f. prak. Geol., 1895.

46 Spence, H. S.: Mica. Canada Dept. Mines Branch, p. 46, 1929.

47 Brögger, W. C.: Die Mineralien der Syenitpegmatit gaüge der Südnorwegischen Augit und Nephelinsyenite. Zeitsch. f. Krys. und Min., 16: 1890.

48 Zeigler, Victor: Differentiation of a granitic magma as shown by the paragenesis of the minerals of the Harney Peak Region, S. D., Econ. Geol., IX: 267, 1914.

49 Stelzner-Bergeat: *Op. cit.*, p. 1148.

50 Butler, B. S., et al: The ore deposits of Utah. U. S. Geol. Surv. Prof. Paper 111: 534.

51 Beyschlag, Vogt, and Krusch: *Op. cit.*, pp. 901–903.

minerals, tourmaline, muscovite, and rarely uraninite and beryl. They occur in close association with granite and quartz diorite, which have been gneisenized after the fashion of tin deposits.

The *commercial* supplies of bismuth are obtained largely as a by-product in the recovery of other metals. It is recovered from smelter fumes at Cerro de Pasco where the copper ores are associated, probably genetically, with a stock of quartz monzonite. It is recovered also from the smelter fumes at the Ashio mine, Japan, where the copper ores occur in and close to a volcanic plug of rhyolite porphyry.

The geologic associations of bismuth and bismuthinite seem therefore to point to genetic relationship with acid and more rarely intermediate, rather than with basic magmas.

Among the rarer components found in some ores of the cobalt-silver type, pitchblende is particularly noteworthy. It occurs sparsely in all of the western Erzgebirge districts and in Cornwall and abundantly at Great Bear Lake, Canada. In these districts there can be little doubt that it was deposited from solutions from the same sources as those from which the cobalt and nickel minerals were deposited.

At Joachimsthal in the Erzgebirge, opportunities for studying underground the relations of pitchblende to the cobalt and nickel minerals are poor, and recourse must be had to museum specimens. In several specimens pitchblende has been deposited on top of cobalt and nickel arsenides. Proustite and calcite commonly coat pitchblende or occupy fractures in it. In two of the mines, the cobalt-nickel-silver ores gave way in depth to quartz-calcite-pitchblende ores carrying a little smaltite, a variation interpreted by Step and Becke [52] as primary. Keil [53] noted that in the ores of Joachimsthal crystalline dendrites of bismuth and of native silver are encrusted not only by cobalt and nickel arsenides but in places by pitchblende. In places, pitchblende encrusts

[52] Step, Josef, and Becke, F.: Das Vorkommen des Uranpecherz zu St. Joachimsthal. Sitzungsberichte der Kaiserlichen Akad. der Wissenschaften. Wien., CXIII: 585–618, 1904.

[53] Keil, Karl: *Op. cit.*, pp. 101–103.

smaltite and elsewhere appears to have crystallized simultaneously with niccolite and rammelsbergite.

At Annaberg and Schneeberg according to Müller [54] the pitchblende is a characteristic though minor component of the cobalt-silver vein type. The conclusion seems justified that in the Erzgebirge the pitchblende was deposited in the same veins with the cobalt, nickel, bismuth and silver minerals and in part contemporaneously with them.

In the well known Dolcath mine [55] of Cornwall, pitchblende occurred " associated with native bismuth and arsenical cobalt in a matrix of red compact quartz and purple fluorspar." At South Tresavean it occurred with niccolite, native silver, and rich argentiferous galena.

At Great Bear Lake, Canada,[56] the pitchblende is closely associated with the cobalt and nickel minerals and seemingly nearly contemporaneous with them.

Other associations of pitchblende may be expected to throw some light on its genetic relationships. Its characteristic occurrence in granite pegmatites is especially well known. It is found in feldspar quarries in such rocks near Middletown, Glastonbury and Branchville, Connecticut, and in mica mines in granite pegmatites in North Carolina. It occurs in the granite pegmatites of Llano County, Texas. Of the pitchblende occurrences described by Ellsworth [57] in Ontario, Canada, nearly all (23 in number) are in granite pegmatite and one doubtful occurrence in syenite pegmatite. He states:—" The radio-active minerals occur apparently mostly and in the greatest abundance in the acid pegmatites. . . . They are less abundant in the intermediate types and are not known to occur at all in the more basic varieties."

[54] Müller, Hermann: Die Erzgaüge des Annaberger Bergreviers, Erlaütermigen zur geologischen Specialkarte des Königsreichs Sachsen, pp. 94, 98–100, 1894; Der Erzdistrikt von Schneeberg in Erzgebirge, in B. Von Cotta's Gangstudien, 3: 129–137, 1860.

[55] Pearce, Richard: Note on pitchblende in Cornwall. Roy. Geol. Soc. Cornwall, Trans., 9: 32–34, 1875.

[56] Kidd, D. F.: *Op. cit.*, p. 158.

[57] Ellsworth, H. V.: Radium-bearing pegmatites of Ontario. Canada, Dept. of Mines, Geol. Surv. Summary Rept., Pt. D: 51–70, 1921; also Summary Rept., Pt. C–1: 7–8, 1925.

Pitchblende occurs in the copper veins of Telemarken, Norway, whose bismuth content and association with intrusive granites has already been noted.[58]

Uranium compounds, probably from the oxidation of pitchblende, occur in granite pegmatites cutting the granite massif of Northern Portugal.[59]

The pitchblende deposits of Gilpin County, Colorado [60] appear to be a variant of the sulphide mineralization of the district and are associated with monzonites, monzonite porphyries and bostonites. There are no basic intrusives near the deposits.

The presence of pitchblende, therefore, strongly favors the view that the deposits in which it occurs were deposited by solutions derived from magmas of acid or at most of intermediate composition. It is notable, however, that not all of the ores of the cobalt-silver type carry pitchblende and that it has not been found in any of the ores of Cobalt or the neighboring Canadian camps.

It is of interest at this point to note the conclusion of de Launay [61] published in 1913. "We have already remarked in considering nickel, that cobalt in spite of its well known analogies with this metal which in turn tends to resemble copper, separates itself sharply in a certain number of its deposits, notably to associate itself with bismuth, uranium, silver and more rarely gold: to pass in a word into the groups characteristic of the acid rocks."

THE RÔLE OF DOWNWARD ENRICHMENT.

The ores of the cobalt-silver type possess certain mineralogic features that should be particularly favorable to the processes of downward enrichment. It is appropriate, therefore, to review the evidence as to its actual importance.

The great efficiency of certain metallic minerals in the precipitation of metallic gold and silver from solutions of their salts

[58] Beyschlag, Vogt, and Krusch: *Op. cit.*, pp. 901–903.

[59] Segaud and Humery: Les Gisemends d'Uranium du Portugal. Ann. des Mines, Ser. 11, 3: 111–118, 1913.

[60] Bastin, E. S., and Hill, J. M.: Economic geology of Gilpin county, Colorado. U. S. Geol. Surv. Prof. Paper 94: 123–125, 1917.

[61] de Launay, L.: Gites Mineraux, II: 607–608, 1913.

was emphasized by Chase Palmer and the writer in an article published in 1913,[62] and attention was directed to experiments along similar lines inaugurated by Skey in New Zealand as early as 1870. Palmer and the writer extended Skey's studies to many other minerals and established quantitatively the nature of several representative reactions including that between niccolite and silver sulphate solution, which is expressed by the equation:

$$2NiAs + 5Ag_2SO_4 + 3H_2O \rightarrow 2NiSO_4 + As_2O_3 + 3H_2SO_4 + 10\ Ag.$$

Later,[63] similar reactions were established quantitatively for smaltite, löllingite, maucherite and safflorite and the general rule was formulated that the arsenides and antimonides of nickel, cobalt and iron are effective precipitants of metallic silver from solutions of its salts, whereas the sulphides, sulph-arsenides and sulph-antimonides of these metals are ineffective.

It seemed at first that these laboratory reactions might explain the extreme richness of many of the cobalt-silver ores in native silver.[64] Upon fuller acquaintance however with the microscopic characters of the silver ores of Cobalt and neighboring camps in Canada it became evident that the native silver was largely primary and that Pleistocene glaciation had eroded away any zones of downward enrichment that may once have existed. The single notable exception to this situation is the Keeley Mine at South Lorraine where, as shown by Bell,[65] the Wood's vein has been protected from glacial erosion and in places shows oxidation (pre-glacial) down to the 480 foot level. The wholly oxidized vein material has been completely leached of its silver but the partially oxidized material adjoining it is extraordinarily rich in

62 Palmer, Chase, and Bastin, E. S.: Metallic minerals as precipitants of silver and gold. Econ. Geol., VIII: 140–170, 1913.

63 Palmer, Chase: Tetranickeltriarsenide, its capacity as silver precipitant. Econ. Geol., IX: 664–674, 1914; also Diarsenides as silver precipitants. Econ. Geol., XII: 209–216, 1917.

64 Bastin, E. S.: Significant mineralogical relations in silver ores of Cobalt, Ontario. Econ. Geol., XII: 233–236, 1917.

65 Bell, J. M.: Deep-seated oxidation and secondary enrichment at the Keeley silver mine. Econ. Geol., XVIII: 684–694, 1923.

native silver. In such materials thin leaves of silver have been deposited on red iron oxide and soft layers of spongy silver rest loosely on top of smaltite.[66] Such silver is interpreted by both Bell and Knight as secondary though its ratio to the primary silver is uncertain.

Certain other districts where ores of the cobalt-silver type occur have not been glaciated and in them it might be expected that evidences of downward enrichment would be found. Actually, the richer zones in these districts having long ago been worked out are no longer open to study and appeal must be made to less direct evidence.

The Erzgebirge lies shortly south of the extreme limit of Pleistocene continental glaciation in Europe. The ores were heavily oxidized near the surface and especially in the Fastenberge near Johanngeorgenstadt the richest silver ores that formed the basis of the early mining prosperity occurred at depths of 150 to 300 feet in a zone 150 to 300 feet thick roughly paralleling the surface. Such a distribution although suggestive of downward enrichment is not however conclusive in the absence of other types of evidence.

The Cornwall district also lies outside the area of Pleistocene glaciation. Many of the gossans with oxidized iron and copper minerals are deep and are succeeded below by rich chalcocite ore that in turn gives way to chalcopyrite.[67] It is probable that downward enrichment in silver accompanied that in copper although no positive evidence is at hand.

The cobalt-silver veins of Chalanches, France, appear to owe their richness in silver in part at least to downward enrichment. According to Ricard [68] the parts of the mine richest in silver were those within the reach of oxidation. He says:

> The richness of silver in the oxidized ores suggests secondary precipitation. This is confirmed by the fact that the silver appears to be thrown down upon the nickel and cobalt arsenides, and often envelopes them

[66] Knight, C. W.: Cobalt and South Lorraine silver areas. Ontario Dept. Mines. 31st Ann. Rep., Pt. II: 210, 1922.

[67] MacAlister, D. A.: *Op. cit.*, p. 377.

[68] Ricard, T. A.: *Op. cit.*, p. 701.

in such a way as to impart to them the rudiments of a nodular structure. The hard undecomposed arsenides contain only small amounts of silver. . . . The nickel and cobalt minerals appear to be primary, and are more persistent than those of silver and gold.

Piepoli [69] found evidence of downward enrichment in the ores of Sarrabus in Sardinia. He concludes that a large part of the macroscopic silver of these veins in the form of sheets, filaments, teeth, balls, etc., is probably secondary. He says:

These veins possess a well-developed cap with several minerals characteristic of this zone among which native silver is often encountered. Consequently one is obliged to admit that mineralizing solutions developed in this zone were able to descend into the subjacent zone and there deposit native silver as well as silver minerals such as argentite, stephanite, polybasite, etc. At the same time it is possible to affirm that at least a part of the native silver . . . is of hypogene origin.

It thus appears that in regions where the normal course of oxidation has not been interfered with, downward enrichment has probably exerted a modifying influence upon the primary silver content of the ores.

PRIMARY NATIVE SILVER.

The gradual accumulation of data has made it evident that in Ontario, in the Erzgebirge, and in some of the less important districts the native silver is in large part at least a primary mineral.

The evidence is in part geologic, based on such features as the richness in silver of certain veins that do not outcrop and hence could not possibly have been subject to oxidation and downward enrichment.[70] Their upper portions are in some instances 300 feet or more below the surface.

In the main, however, the evidence is mineralogic, from the paragenesis of the minerals as revealed by the microscope. Such studies have been made on the ores of the Erzgebirge, of Ontario and of several less important districts. They reveal marked similarities between these districts not alone in the kinds of minerals present but in their relations to each other. It is imprac-

[69] Piepoli, M. P.: *Op. cit.*, p. 293.

[70] Whitehead, W. L.: The veins of Cobalt, Ontario. ECON. GEOL., XVI: 1920.

ticable here even to summarize all these mineral relationships but some that have particular genetic significance should be mentioned.

One of the most characteristic features observed in the ores both of Ontario and of the Erzgebirge is the occurrence of native silver and native bismuth in skeleton crystals enclosed by crusts or shells of cobalt, nickel or more rarely iron arsenides. In the Erzgebirge [71] skeletal crystals of bismuth may be encrusted by rammelsbergite, safflorite or smaltite, and silver may be encrusted by these or by niccolite or pitchblende. In Ontario, skeleton crystals of silver may be encrusted by smaltite, safflorite or arsenopyrite. At Wickenburg, Arizona, silver crystals are encrusted by chloanthite or by niccolite. The crystal forms assumed are those characteristic of bismuth and native silver; they must therefore be interpreted as older than the layers of primary cobalt and nickel arsenides that encrust them and hence as themselves primary. Minute inclusions of silver abundant in places in the arsenides must also be interpreted as primary in the absence of any evidence that they have formed by replacement. Hence a portion of the native silver of these deposits is unquestionably an early primary deposit.

Some of the native silver at least in the Ontario deposits is, however, of later formation since it traverses the arsenides in the form of well-defined veinlets. Yet the silver of these veinlets also appears to be primary for the veinlets are hybrids made up of alternating segments of silver and calcite—neither mineral a replacement of the other. Moreover, as occasional components irregularly intergrown with the calcite and silver of these veinlets occur niccolite, breithauptite, chalcopyrite, tetrahedrite and sphalerite. Such a mineral association is unknown and extremely unlikely as a secondary deposit from descending meteoric waters. Thus, it must be concluded that much of the native silver of the ores of the cobalt-silver type is a primary deposit from hydrothermal solutions. The possibility and even the probability of downward enrichment having been operative in certain situations

[71] Keil, Karl: Beiträge zur Kenntnis der Kobalt-Nickel-Wismut-Silber Erzgaüge. Jahrb. f. das Berg- und Hüttenwesen in Sachsen, p. 105, 1931.

must be recognized for the reasons outlined earlier in this paper but as yet no supporting microscopic evidence has been found.

TEXTURES INDICATIVE OF DIFFUSION.

A further feature that is common to many of the ores of the cobalt-silver type is the prevalence of textures that may be termed dendrites of concentric structure. These are branching masses of metallic minerals in a matrix of carbonate, each branch showing a concentric arrangement of its components much as a twig shows rings of growth. Around the nucleus may be one band or in rare cases as many as five or six. These textures have been interpreted, correctly or otherwise, as formed by the diffusion of the metallic components through a gel prior to the reorganization of the minerals into their present crystalline forms. Textures of this sort seem to be equally characteristic of the ores of Cobalt and neighboring camps, of Silver Islet and of the Erzgebirge. They constitute another unifying feature of this ore type.

THE ENIGMA OF THE ONTARIO DEPOSITS.

Of the districts listed in Table I, where veins of the nickel-cobalt-native silver type occur, data suggesting a genetic relation of the ores to specific types of igneous rocks are lacking for nearly half of them. In Cornwall, the Erzgebirge, Sardinia, Great Bear Lake in Canada, Sabinal and Batopilas, Mexico and Balmoral, South Africa, the field associations point clearly to a genetic association of the ores with granitic intrusives. Cobalt, Ontario, and its neighboring camps is the only region in which the ores of this type are in close association with diabases and granites are absent. It is of importance for the clarification of our understanding of ore genesis to inquire whether the Ontario occurrences constitute a unique exception to the general mechanism of ore genesis for this type.

The ores of the Ontario districts resemble the European occurrences remarkably closely in mineral composition and textures. Their association with the Nipissing diabase has been so in-

variable and so close as to create a strong presumuption that the diabase or diabasic magmas were the source of the mineralizing solutions and this has been the widely accepted conclusion. It is desirable to consider whether the association may not be otherwise explained.

Enquiry may first be directed to the probable structural influence of the diabase sills on mineralizing solutions. The sediments of the Cobalt series and the sills of Nipissing diabase that in a general way tend to parallel them, together constitute a structural partnership of formations of great horizontal extent but of relatively small thickness. The principal area in Ontario that is blanketed by these formations is roughly 5000 square miles in area and about 70 miles across from east to west. The thickness of the diabase sills in this area ranges from 800 to 1250 feet and

FIG. 1. Diagram illustrating approximate dimensions in cross-section of the Cobalt Series and associated sills of Nipissing diabase.

of the sediments 2500 to 3500 feet.[72] On a scale of 20 miles to the inch for both horizontal and vertical dimensions the blanket of nearly horizontal sediments and diabase would have about the cross-section shown in Fig. 1. The Cobalt series and the Nipissing diabase form a relatively brittle and nearly horizontal covering over the older formations that are either much metamorphosed and highly inclined sediments and volcanics or else massive plutonics of batholithic proportions. These relations would seem to be particularly favorable to extensive cross-fracturing of the Cobalt formation and the diabase in warping movements of regional extent. The localization of fracturing within these formations would be a favorable structural antecedent to the later localization of ore deposition within them irrespective of other

[72] Collins, W. H.: North shore of Lake Huron. Geol. Surv. Canada. Mem. 143: 111, 1925.

possible relationships of the Nipissing diabase to the mineralizing solutions.

Furthermore, the flat-lying position of the Cobalt series, which appears to have been so potent an influence in causing the rising diabase magmas to spread laterally into sills, may be expected to have been favorable also to a large lateral component of movement in the later mineralizing solutions—a tendency likely to be further accentuated by the sill-like forms of the diabase intrusions. In support of the importance of structural control it should be noted that at Cobalt, according to Knight,[73] the contact between the Cobalt series and the Keewatin has controlled the location of 80 per cent of the ore and in most of the mines the ore shoots did not rise more than 100 to 200 feet above this contact.

But the close association of diabase and ores has been interpreted as implying *more* than the existence of structural conditions favorable to mineralization. It has been held to imply that the mineralizing solutions came either from the diabase sills or from the same deep-seated source from which the diabase magmas rose. These two alternatives, mentioned in the same sentence, carry, however, widely different genetic implications.

The first alternative postulates that the mineralizing solutions came from the sills themselves after they have become completely solidified and were cut by fractures, due not merely to cooling but to orogenic forces, arranged in more or less regular sets and including some faults of considerable displacement. The hypothesis implies the derivation of the mineralizing solutions from a rock of quartz diabase composition. The solutions may be variously regarded as the highly aqueous residuum after the crystallization of the diabase or as carrying also components redissolved from the diabase. The hypothesis accords with the close association of the ores with the diabase but has the serious weakness of postulating for the ores of Ontario processes that are clearly not applicable to ores of nearly identical mineral composition and textures found in other parts of the world. It postulates that the

[73] Knight, C. W.: Geology of the mine workings of Cobalt and South Lorraine silver areas. Ontario Dept. Mines, 31, Pt. 2: 7, 1922.

metals have been leached from the solid diabase and redeposited in fractures in the diabase or its bordering rocks all within a rock body of roughly the dimensions shown in Fig. 1. It derives no support from studies of the composition of the diabase. E. S. Moore [74] collected samples of the diabase away from known veins in the Cobalt, Gowganda and South Lorraine Districts. Very careful analyses of these samples showed a silver content ranging from .013 to .047 ounces per ton. These silver values are of the same order of magnitude as the silver content of supposedly fresh syenites, granites and basalts from the western United States which have been carefully assayed and are not associated with any ore deposits.[75]

The alternative hypothesis that the mineralizing solutions came not from immediately associated diabase sills but from a somewhat more remote magmatic source is more accordant with the occurrence of cobalt-silver ores in Europe and elsewhere. It does not exclude the derivation of the solutions from quartz diabase magmas lying deeper than the sills and constituting their sources, but neither does it exclude their derivation from more acid magmas related or unrelated genetically to the diabase but not reaching the present surface. Certain evidences pointing to a derivation from acid magmas will here be presented.

In a paper published in 1935 [76] the present writer summarized previous interpretations of certain red rocks or so-called "aplites" associated with the silver veins in Nipissing diabase notably at Gowganda and Elk Lake and presented a new interpretation of their origin based upon additional field and laboratory study. The characters and relations of the "aplites" as determined by previous writers have already been summarized, but the supplementary studies of the present writer will also be summarized

[74] Moore, E. S.: Genetic relations of silver deposits and Keweenawan diabase in Ontario. ECON. GEOL., XXIX: 752–753, 1934.

[75] Lincoln, F. C.: Certain mineral associations of gold. ECON. GEOL., VI: 250–254, 1911; also Wagoner, Luther: The detection and estimation of small quantities of gold and silver. A. I. M. E., Trans., XXXI: 798–810, 1901.

[76] Bastin, E. S.: "Aplites" of hydrothermal origin associated with Canadian cobalt-silver ores. ECON. GEOL., XXX: 715–734, 1935:

as they have an important bearing on the source of the vein-forming solutions.

The dike-like " aplites " have generally been interpreted as true dikes representing the final product of the crystallization of the Nipissing diabase magmas. Since they border the veins and in places grade into vein material, this led some geologists to the view that the veins represented the final products of the crystallization of the diabase magmas. In the paper referred to the writer presented evidence to show that the " aplites " were not crystallizations from a magma but were products of hydrothermal replacement of the Nipissing diabase by solutions moving out from the vein fissures into their walls. The mineralogical changes that accompanied these replacements are presented in detail in Table II. Somewhat similar hydrothermal alterations were shown to have affected also some of the sediments associated with the veins and the diabases.

Field and microscopic evidences combine to indicate that the Nipissing diabase sills were not only completely crystallized but also considerably fractured and in places faulted prior to the development of the " aplite " and the ores. It is unlikely, therefore, that the sills themselves were the source of the mineralizing solutions.

If, as seems probable, the mineralizing solutions came from a deep-seated magmatic source what was the composition of these magmas? The time interval between the intrusion of the diabases and vein formation was sufficient to permit widespread warping and faulting of the diabase and its associated sediments. There is, therefore, no *a priori* reason for believing that the mineralizing solutions came from a magma of diabasic composition. All of the minerals of the diabase except quartz and orthoclase (and accessory apatite) were notably unstable in the presence of the mineralizing solutions and chemically the alterations involved the addition of water, soda and the carbonate radicle and oxidation of ferrous iron to the ferric state with the formation of finely divided hematite that imparted a pink color to the feldspars. In some of the veins at Gowganda and Elk Lake, quartz is the prin-

TABLE II.

SEQUENCE OF MINERAL CHANGES IN HYDROTHERMAL ALTERATION OF NIPISSING DIABASE TO "RED ROCK" AND "APLITE." Arrows indicate the course of the alteration.

Theoretical Unaltered Granophyre Diabase	Least Altered Granophyre Diabase (Spec. 16)	More Altered Granophyre Diabase (Specs. 29, 37)	Gray to Mottled Facies Bordering "Red Rock" or "Aplite" (9a, 27a, 28a)	"Red Rock" of Irregular Bodies (Specs. 4, 7 and 8)	"Aplites" of Dike-like Form (9b, 27b, 28b)
Labradorite	Labradorite → Fine white mica	Fine white mica → Albite	Albite	Albite	Albite
Albite? Quartz } graphic	Albite Quartz } graphic	Albite Quartz } graphic	Albite Quartz } graphic	Albite Quartz } graphic	Albite Quartz } graphic
Augite	Augite → Hornblende and Biotite → Chlorite	Augite → Hornblende and Biotite → Chlorite	Chlorite	Chlorite	Chlorite (sparse)
Titaniferous Magnetite	Titaniferous Magnetite	Titaniferous Magnetite	Titaniferous Magnetite → Leucoxene	Leucoxene	Leucoxene → Titanite
Titanite	Titanite	Titanite	Titanite	Titanite	
Apatite	Apatite	Apatite	Apatite	Apatite	Apatite
Garnet	Garnet	Garnet			
			Calcite	Calcite	Calcite (abundant)
		Pyrite	Pyrite	Pyrite	Pyrite
			Chalcopyrite	Chalcopyrite	Chalcopyrite
			Bornite		Bornite
				Specularite	Specularite

cipal gangue and analyses of the "aplites" [77] show notably more silica than is characteristic of the Nipissing diabase. Nothing in the mineralogical or chemical nature of these changes seems definitely to connote derivation of the solutions from magmas of diabasic composition.

Although at Cobalt and neighboring camps, *acid* intrusives younger than the Nipissing diabase have not been found, there is one Ontario district in which younger granite occurs and is associated with ores. This area is Bruce Mines on the north shore of Lake Huron and despite the fact that it lies 150 to 175 miles southwest of the Cobalt-Gowganda areas it will be pertinent to consider the geologic relations there displayed. In spite of remoteness, the Bruce Mines area resembles the Cobalt-Gowganda areas in several particulars. First, the presence of a sedimentary series that closely resembles the Lorraine series of Cobalt and like it has been classed as Animikean; second the presence in these sediments of sills of diabase that closely resemble the Nipissing diabase and have been so correlated; third, the presence of mineral veins that in a few places carry cobalt, nickel and silver minerals; [78] and fourth, the presence in the diabase walls of the veins of hydrothermal alterations identical with those observed in the Gowganda, Cobalt and South Lorraine districts.

Attention has already been directed to the fact that at Gowganda and Elk Lake the dominant cobalt-silver veins show transitions into veins carrying chalcopyrite, bornite and pyrite. At Bruce Mines it has long been known that the converse relation obtains and that at a few places the dominant copper veins carry also cobalt bloom, cobaltite and native bismuth and on assay show fair silver values.[79] The similarities are sufficient to suggest similar conditions of ore genesis.

In his report on Bruce Mines above referred to, Knight [80] notes that the veins traverse Nipissing diabase and are cut by dikes of

[77] See page 15.

[78] Knight, C. W.: The north shore of Lake Huron. Ontario Bur. Mines. 24th Rep. Pt. I: 216–241, 1915.

[79] Knight, C. W.: Idem, p. 238.

[80] Idem, p. 231.

later diabase. He regards them, therefore, as of about the same age as the cobalt-silver veins at Cobalt.

In the summer of 1937 the present writer noted dikes of pink granite traversing the Nipissing diabase at two localities at Bruce Mines and these dikes are in turn cut by the copper veins. The first locality is near an old mine shaft ¼ mile southeast of the Bay View Hotel. Here a dike of pink pegmatitic granite 2 to 3 inches wide sharply cuts the diabase and is traceable for 40 feet. The second locality is a little farther southeast in the Martin trap rock quarry near the east side of the bay. Here a 10-inch vertical dike of pink medium-grained granite sharply cuts the diabase on the north side of the quarry pit. Both granite and diabase are cut by one of the typical veins of the region characterized by quartz, siderite, chalcopyrite and bornite. It is noteworthy that cobalt bloom has been found coating diabase in this quarry.[81]

The microscope shows that the 2 to 3 inch dike is a granular intergrowth dominantly of orthoclase and microcline. Quartz was not present in the slide but was abundant in places in the central portions of the dike. Secondary minerals are tremolite in radiating aggregates and a carbonate (probably siderite). Titanite and leucoxene are probably alterations of titaniferous magnetite. Determined as granite altered hydrothermally to develop tremolite, carbonate and titanite.

The 10-inch dike in the trap rock quarry showed under the microscope a texture dominantly granular but with micrographic intergrowths of quartz and feldspars abundant. The feldspars are orthoclase, microcline and albite. No primary ferric minerals remain but chlorite is fairly abundant. Part of the chlorite probably replaces original femic minerals but some replaces feldspars and even quartz. Some secondary carbonate replaces feldspar. Determined as a granite somewhat altered hydrothermally with the development of chlorite and carbonate.

Analogous relations were observed by the writer in the banks of Mississagi River a short distance above the Mississagi railroad bridge. There dikes of pink granite sharply cut diabase sills and are in turn cut by quartz veins.

The Nipissing diabase at Bruce Mines, like that at Gowganda, Cobalt and South Lorraine, has been hydrothermally altered next the veins and the alterations are severe and of the same sort as at these camps.

[81] Knight, C. W.: Idem, p. 239.

Alterations of the diabase next the veins were studied at the old shaft at Bruce Mines village, about ¼ mile north of the Sault Ste. Marie highway. One of the fresher facies of the diabase here is a granphyric diabase in which the plagioclase is little altered labradorite (above balsam in index and with maximum extinction angles up to 40°). Augite has been partly altered to hornblende and biotite and these in places have further altered to chlorite. Grains of gray metallics are intergrowths of two minerals probably magnetite and ilmenite. The feldspar of the graphic intergrowths with quartz is orthoclase (unstriated and below balsam in index).

A still fresher facies from this locality is an olivene diabase in which the only alteration is a partial change of olivene to antigorite.

Within a few inches of the vein the diabase has been so highly altered that few of its original minerals remain although the granophyric diabasic texture is still preserved and the rock has the megascopic appearance of diabase. Many plagioclase laths are clouded with fine flakes of white mica especially in their interior portions; this is probably paragonite. Where clear and determinable the plagioclase is albite. Feldspar in graphic intergrowths with quartz is still orthoclase. Original ferric minerals are completely altered to chlorite and titaniferous magnetite to leucoxene.

In immediate contact with the vein the altered diabase assumes a somewhat pinkish color tone. Plagioclase is all albite and is entirely free from mica flakes. Original femic minerals have completely altered to chlorite and titaniferous magnetite to leucoxene of two color tones. Some bending, faulting, and even granulation of the feldspars has locally taken place especially near tiny veinlets that traverse the rock and are evidently off-shoots from the main vein. These veinlets carry quartz, carbonate, chalcopyrite and bornite. Considerable secondary carbonate also replaces feldspar.

The wall-rock alterations were also studied at the old mine shaft ½ mile southeast of the Bay View Hotel at one of the granite dike localities. Here at a distance of 1½ feet from the vein the rock although retaining a granophyric diabasic texture has been greatly altered. Flakes of fine white mica cloud the interior of the plagioclase laths but the exterior portions are albite. Original femic minerals and part of the albite have been replaced by chlorite. Titaniferous magnetite has altered to leucoxene. In places there is bending, fracturing and even granulation of the albite. In immediate contact with the vein the original texture of the diabase is still preserved but the feldspars have a pinkish tone and are mostly clear albite free from mica flakes. Chlorite is the only femic mineral and probably occupies mainly the places once filled by augite, though some is a replacement of feldspar. Leucoxene is probably secondary after titaniferous magnetite. Bending, fracturing and granulation of the feldspars is more extensive than in the specimen taken farther from the vein.

It is evident from the above descriptions that in the hydrothermal alteration of the diabase by the mineralizing solutions in the Bruce Mines district, labradorite is altered first to a felt of fine flakes of white mica (probably sodic) and then to clear albite.

Augite alters first to hornblende and biotite and these in turn to chlorite, titaniferous magnetite alters to leucoxene. Quartz and orthoclase of the granophyric intergrowths remain unchanged. In the later stages of these alterations the feldspars assume a pinkish color and impart a pinkish tint to the rock.

These changes are similar in all respects to those observed near the veins of Cobalt, Gowganda and South Lorraine and displayed in Table II. Doubts were expressed upon chemical grounds as to whether in these districts the mineralizing solutions came from diabasic magmas. At Bruce Mines the same objections would hold but there is the additional fact that granite intrusions intervened between the emplacement of the diabase and the formation of the veins. Further, these granite dikes show evidences of hydrothermal alteration though less severe than in the diabase. In the Bruce Mines area, therefore, the mineralization followed the intrusion of both Nipissing diabase and granite but preceded the intrusion of younger diabase dikes. It is logical to connect the mineralization genetically with the Keweenawan igneous activity but it is equally if not more likely that the magmatic source was granitic rather than diabasic.

Published descriptions of the rocks of Pigeon Point, Minnesota, along the Ontario border, suggested that the diabase sills of that region were associated with certain rocks that closely resembled the "aplites" of the Gowganda, Elk Lake and Bruce Mines areas and were also associated with granites. The writer, therefore, visited Pigeon Point in August 1936 and the results of his studies have recently been published.[82] These studies indicate that the Keweenawan diabase sills that intrude the sediments (Rove formation) of Pigeon Point have in turn been intruded by granite. The granite contact metamorphosed the sediments and locally the diabase. Subsequently diabase, granite and sediments were hydrothermally metamorphosed over large areas. It is significant to note that the hydrothermal alterations in the diabase sills were severe, affecting nearly all the minerals of the

[82] Bastin, E. S.: Hydrothermal alterations in the rocks of Pigeon Point, Minnesota. Jour. Geol., XLVI: 1058–77, 1938.

rock and that they were of precisely the same character as those observed near the veins at Gowganda and at Bruce Mines and displayed in Table II. Hydrothermal alterations in the granite and in the sediments were less severe and the dominant components of the granites, quartz and orthoclase seem to have been stable in the presence of the thermal solutions. It is clear that the hydrothermal metamorphism was later than the intrusion of both diabase and granite. Under what must have been essentially identical conditions of temperature and pressure the granites were much more stable in the presence of the thermal solutions than were the diabases. It seems probable that the thermal solutions came from a deep-seated magmatic source and that this source was granitic rather than diabasic in composition. It is possible also that the solutions had their source in a magma of intermediate composition that was the parent magma of both diabases and granites.

The evidence presented toward a solution of the enigma of the Ontario deposits may be epitomized as follows:

The prevailing association of the nickel-cobalt-silver veins with relatively flat-lying diabase sills is probably due in part to a blanketing effect of the sills and the associated flat-lying Cobalt series on ascending mineralizing solutions causing them to spread laterally beneath these formations until they encountered fractures suitable for ore deposition.

The Nipissing diabases were not only completely crystallized but had been fractured by faults, some of them of considerable displacement, prior to mineralization. It is unlikely, therefore, that the mineralizing solutions came from the diabase sills.

This conclusion is also supported by evidence that certain so-called aplites that border some of the veins are not the final products of the crystallization of the diabase sills as formerly believed but were formed by hydrothermal alteration after the diabase was completely solidified.

If the mineralizing solutions came from a deep-seated magmatic source there is some evidence that this source was granitic (or possibly intermediate) in composition rather than diabasic and

that the Ontario ores are *not* an exception to the general rule of the genetic relationship of ores of this type with granitic intrusives. The first evidence consists in the presence in the Bruce Mines area of granites younger than the diabase sills but older than the mineralization. The second evidence consists in the profound alterations produced in the diabase by the mineralizing solutions indicating vigorous chemical interaction. These alterations are of precisely the same sort that in the Bruce Mines area and at Pigeon Point, Minnesota, followed granitic intrusions. In these two districts the mineralizing solutions produced comparatively mild alterations in the granites. It seems probable that in the Cobalt and neighboring districts as well as at Bruce Mines and at Pigeon Point the solutions which deposited the ores and hydrothermally altered the rocks came from magmas of granitic or at most intermediate composition.

THE UNIVERSITY OF CHICAGO,
October, 22, 1938.

DIASCHISTIC DIKES AND ORE DEPOSITS.

J. E. SPURR.

THE close relationship of basic dikes to many ore deposits was the subject of a paper I published in 1925.[1] I remarked in part:[2]

> Ordinary ore intrusion constitutes the last of the magmatic injections in a given igneous center, which center is very often marked by evidences of magmatic differentiation. But there are frequently recurring cases where scanty dike injections are contemporaneous or even later than the ore injections. These latest rock magma injections are so often basic dikes, in part lamprophyric, as to attract attention and examination of the data.

After citing a number of cases from geological literature, I summarised the facts as showing that basic dikes, in part lamprophyres, occur in close relation to many ore-deposits; that, in many cases such dikes are later than gold-quartz veins (for example), which themselves are later than granite or other major intrusions; while in other cases, such dikes were essentially contemporaneous with the final (sulphide) phase of introduction of the gold-quartz ore-magma. Similar relations have been described for ores of other metals, including zinc and lead, copper, and even nickel.

Taking gold-quartz veins as a convenient type, it has been repeatedly pointed out by many geologists[3] that the gold and accompanying sulphides are generally deposited later than the bulk of the quartz, in rifts or cracks in the quartz or along the walls or in independent fissures; or the quartz veins may not have undergone this final stage, and be barren.[4]

From these occurrences of basic dikes intimately associated in point of time with ore introduction, I argued that the temperature

[1] Basic dike injections in magmatic vein sequences. Geol. Soc. Am. Bull. 36: 545–582, 1925.

[2] Op. cit., p. 576.

[3] Op. cit., p. 550; Spurr, J. E.: Geology Applied to Mining. McGraw Hill Co. 2nd Ed., pp. 136, 294, 324, 1926.

[4] Spurr, J. E.: Geology Applied to Mining, p. 530.

of consolidation of the basic dikes and the ores corresponded closely; and hence made suggestions as to this temperature, placing tentatively the range as between 400 and 500° C.

After describing type occurrences, I added: "The number of cases of gold-quartz veins associated with diabase (commonly later) are so numerous that it would be tedious to enumerate them further."

In many cases (still narrowing our attention, for the sake of convenience, to gold-quartz veins), geologists have observed a close relation in the field between the basic dikes and the richer ores; in many other cases no such relation has been reported.

I did not, in my paper above cited, infer any genetic relationship between the ores and the intimately associated basic dikes. In an earlier writing,[5] I referred to

> plutonic gold-quartz veins, which may occur near or on the contact of basic (diabase) dikes, which are one of the results of rock differentiation, whereas they are really genetically related not to these, but to the alaskitic and pegmatitic dikes which are complementary to the diabase as rock differentiation products.

And in discussing the gold-quartz veins of Victoria, Australia, as described by Junner,[6] I observed that the rare juxtaposition of the veins with basaltic dikes "is plainly fortuitous, unless at times there may be some coupling on account of vein and dike being complementary—siliceous and basic extremes of differentiation."[7] In these observations, it will be seen later, I just missed the point of view which I am presenting in this paper.

Since writing the above essays, as I have looked over the abundant descriptions of ore-deposits that have more recently appeared, the repeated occurrence of new cases of ore-deposits closely associated in time and place with basic dikes (mostly small ones) has been so insistent that it seems difficult not to believe that there is a more definite reason for this association. The ghost keeps popping up, and will not be laid.

[5] The Ore Magmas. McGraw Hill Co. p. 383, 1923.
[6] Junner, N. R.: Econ. Geol. XVI: 83, 1921.
[7] The Ore Magmas, p. 594.

That there lies in this association a clue to the genesis of ores was advocated by Hulin.[8] He pointed out that

> basic intrustive igneous rocks occur associated with ore deposits almost as frequently as do acid intrusive igneous rocks, though usually in considerably less volume. . . . There is a very common sequence of (1) intrusion of acid igneous rocks; (2) intrusion of basic igneous rocks; and (3) formation of ore deposits. This sequence is so commonplace that it must be recognized as being something more than a coincidental condition. . . . It can be stated confidently that the vast majority of mineralized regions contain both basic and acid intrusive rocks which have been injected just prior to, and in some cases contemporaneous with, the mineralization.

His review, which was only a partial one, covered one hundred and twenty of the more important mining camps of North America, showing the introduction of basic dikes "at about the time of mineralization," and twenty-four important camps outside North America.

Most of the instances in his tabulation showed the sequence: (1) minor acid intrusives; (2) minor basic intrusives; and (3) ore deposition. Usually this association is preceded, he states, by major intrusives of intermediate to acid composition. But in many cases the sequence of these three events is different; often the basic dikes are essentially contemporaneous with the ore; and in some rarer cases the basic dikes have preceded the acid ones.

Assuming the likelihood of a genetic significance in the close association of this intrusive, injected, or introduced trio, it remains to formulate a theory, or working hypothesis to explain or partly explain it. Hulin points out the fact, above referred to, that there are two discernible stages in the history of gold-quartz veins, for example—an early stage of more or less barren quartz, and a subsequent stage characterized by the introduction of metallic sulphides and gold. He then proposes to link the quartz with the acid intrusives, the sulphides and gold with the basic intrusives, and to believe that the former was deposited from a "salic differentiate," the latter from a subsequently introduced "basic differentiate." There is reason to believe," he writes, "that these two associated groups represent acidic and basic differen-

[8] Metallization from Basic Magmas. Univ. of Cal. Pubs. Dept. Geol. Bull. 18: 233–284, 1929.

tiates respectively from a common magmatic source, though probably from individual residual reservoirs."

From my own point of view, the hypothesis of Hulin is difficult to apply. Granted the well-established usual succession of quartz veins followed by metallic ores, nevertheless the close association of the two indicates that they have a common source, and are stages of deposition from a common or closely related though changing magmatic solution.

Leaving out of consideration for the moment the ore (quartz and metallic minerals) members of this noteworthy trio, the common close association, in place and geologic time, of small acid and basic dikes, following a major intrusion, has been generally accepted as resulting from differentiation from the magma; and they have been held to be complementary, resulting from the parent magma, or a part of it, having separated out into two opposed but complementary parts. Niggli,[9] for example, writes:

> Almost as constant associates of the granite as the aplites, are the lamprophyres, which are silica-poor products of differentiation. The after-intrusion of these is as a rule later than that of the aplites. Not infrequently they are especially common in the peripheral portions. Doubtless the mineralizers, especially H_2O, play a role in the differentiation of this fractional magma. This is indicated by the usually high content of biotite or hornblende. . . . Aplite and lamprophyre, in contrast with the main intrusive, have a complementary relation. But it is hardly probable, that it is a matter of simple splitting of the magma into two fractional magmas. To go into the whole complex of questions, would lead too far.

Indeed, while it is convenient to group the products of differentiation in a certain case in a two-fold classification such as " acid " and " basic," or " salic " and " femic " and the like, yet the actual products of differentiation may also be more carefully classified into a three-fold up to a manifold division. Actually, if we group together various instances, it is shown that differentiation may proceed so far as to segregate by itself each mineral.

In this problem it must be recognized that the lamprophyric dikes, characterized by large amounts of hornblende or mica, must be grouped together with the other basic dikes that occur in the

[9] Die Leichtflüchtigen Bestandtheile im Magma. P. 130, Leipsig, 1920.

condition already specified, which dikes are variously reported as diabase, diorite, trap, basalt, and the like.

Considering now separately the association, in the groups under review, of acid dikes and quartz veins, there are, as has been many times pointed out, transitions exhibited between granites and alaskites (quartz-feldspar rocks, whether pegmatite or aplite, or of a granitoid texture) and between alaskites and quartz veins. Where aplites and quartz veins occur together as independent injections, therefore, their common origin is generally a safe assumption.

There is, therefore, a likelihood that the acid dikes, the quartz veins, the metallic minerals, and the basic dikes, in many of the cases under consideration, are all, so to speak, separate differentiation products grouped so closely together in space, in time of intrusion, and generally in respect to quantity, as to indicate that they have been derived from a relatively small sub-magma that remained fluid after the consolidation of the major (generally intermediate in composition) magma, and thereafter split into the various injections in the grouping.

These diverse products must have remained fluid, although in practically the same reservoir, up to and during the general period of their intrusion: this is shown by the changing order of injection in different districts, which is in places completely reversed; and by the frequent essential contemporaneity of introduction of different members of the group, as, for example, of the basic dikes and the ores.[10] Before the differentiation into the (relatively speaking) end-products represented by the dikes, veindikes, and veins, which are under consideration, there must have existed, then, a relatively small sub-magma containing most of the materials exhibited by the related major intrusive; but, in addition, a larger and vastly disproportionate amount of the metals and other rarer elements, of the volatile elements, and (at least in the case of districts showing gold-quartz veins), of silica.

[10] Spurr, J. E.: Basic dike injections in magmatic vein sequences. Geol. Soc. Am. Bull. 36: 552, 1925.

The segregation and consequent high content of volatile elements may be held responsible for the segregation of this sub-magma from or through the main intrusive mass; for the maintainance of its fluidity after the main mass had solidified; and for the relatively swift segregation, after its having been collected or impounded, into the end-products that form the groupings under discussion—the closely related acid dikes, basic dikes, quartz veins, and metallic minerals.

As to the complementary acid and basic dikes, Daly writes:[11]

> Diaschistic dikes . . . are peculiar in chemical composition and their magmas are not represented in stock, batholith, great laccolith or lava flood. The so-called complementary dikes are the relatively minute products of magmatic splitting that has doubtless taken place according to methods different from those responsible for the larger rock-bodies. The complementary dikes . . . seem to find best explanation in two different principles: gaseous transfer, and the 'squeezing out of residual magma' in the freezing stage of an abyssal wedge or of its satellite.

I add an observation of Tolman and Rogers:[12]

> The role of mineralizers in magmatic differentiation has not been sufficiently emphasized. The crystallization of the early formed minerals in the magma involves the complementary process of the 'squeezing out' of the residual fluid. This process is not merely a mechanical one, but is also due to gaseous extraction.

Variations in the local representation of the various products of this sub-magma differentiation into complementary dikes, veindikes and veins, in any given district will be conditioned by physical and chemical differences. On the physical side, one or more of the products may fail of appearance because of the lack of the formation of a convenient penetrable fissure at the critical time. There may be, therefore, any combination of these products represented, any combination missing. On the chemical side, the relatively volatile sub-magma and its associated major magma may or may not coincide with a metallographic (metallogenic) province. If there is not this coincidence, the products may display the complementary (diaschistic) dikes, including pegmatites and quartz veindikes and veins, but no ore-bodies. Secondly,

[11] Igneous Rocks, McGraw-Hill Co., p. 444, 1914.

[12] Study of the Magmatic Sulfide ores. Stanford Univ. Pubs., p. 72, 1916.

and also on the chemical side, the final products of differentiation will vary with the nature of the major magma province. Conspicuous quartz veins, for example, will result in regions of siliceous or intermediate magmas. Where there is little or no free silica (not needed to combine in silicates) in the associated major intrusions, quartz veins may be inconspicuous or lacking. This evidently does not prevent the differentiation and emplacement of the metallic ores.[13] As a minor example, I refer to the gold-mine at Holguin, Cuba,[14] in a basic diorite region. Here there are minor dikes of aplitic texture, some light-colored, some dark; the lighter ones are albitite or soda-trachyte, the darkest ones hornblendite. An albitite dike has been crushed, and in the fracture planes has been deposited gold and a little pyrite. Quartz, so far as I observed, is absent; the scanty gangue consists of calcite.

Contemplating further the suggested relation of closely associated basic and acid dikes, quartz veins and gold ores (for example), it will be natural that in some cases overlapping of the typically distinct products will occur. The overlapping of metallic ores and quartz veins is the commonest case, since these are evidently closely associated members of the differentiation group. But in many cases this merging is partly or largely a mechanical one, and not necessarily the result of the injection of a magmatic product intermediate between the two: the ores, as pointed out above, may be partly or mainly subsequent, and have filled cracks in the quartz. Less common, but still not extraordinary, are auriferous aplites and pegmatites. In these cases also, the combination of ore and aplite or pegmatite is probably generally mechanical, as in the Holguin case cited above, and in many more typical cases that are on record. Still less commonly, perhaps, the basic dikes are auriferous, as notably the case in Guiana; and the same remarks apply to these also. In Guiana, auriferous aplites, auriferous quartz veins, and auriferous diabase have been worked in different mines. In French Guiana, "Quartz veins cut the

[13] The Ore Magmas, p. 590.

[14] Op. cit., p. 612.

ancient metamorphic rock in many places, but most are barren, except those associated with the more recent intrusions of diabase or diorite." [15] In certain cases on record, as at Waverley, Victoria, Australia,[16] the gold in a basic dike is in quartz veinlets, which are later than the dikes.

On the other hand, where segregation in the sub-magma has not been complete, these dikes of aplite and pegmatite, and of basic rocks, may rarely contain contemporaneous gold and other metals, generally in relatively small amounts, and examples of these instances are to be found in geological literature; whereas metals truly contemporaneous with the quartz veins will be still more commonly found.

It should go without saying that the hypothesis roughly outlined above, although it does not so specify, is without prejudice to more detailed phenomena, such as the complex history of pegmatite and aplite crystallization, involving replacement, as shown by many fine studies, for example that of Derry; [17] and the similar detailed succession of crystallization of quartz veins and of ore-deposits, as determined by many investigations. Indeed, important succession of crystallization, involving replacement, may and does occur even in plutonic igneous rocks.

ALSTEAD, N. H.,
September 26, 1938.

[15] Miller and Singewald. Mineral Deposits of South America, McGraw-Hill Co., 1919.

[16] Phillips and Louis. Cited by Beyschlag, Vogt, and Krusch, Trans. by Truscott, MacMillan, vol. 2: 616, London, 1916.

[17] Derry: The genetic relationships of pegmatites, aplites, and tin veins. Geol. Mag. LXVIII: No. 808, 1931.

THE PYROSYNTHESIS, MICROSCOPE STUDY AND IRIDESCENT FILMING OF SULPHIDE COMPOUNDS OF COPPER WITH ARSENIC, ANTIMONY AND BISMUTH.

A. M. GAUDIN AND GÜNTHER DICKE.

ABSTRACT.

The sulpho salts of copper with arsenic, antimony and bismuth have been synthesized and studied under the microscope, selective iridescent filming being applied wherever useful.

Many data have been secured as to the composition, solid-solubility, formation temperatures and melting points, and mutual relationship of the phases.

A correction is proposed for the formula of cuprobismutite.

PART I

As a part of the general research program of pyrosynthesizing sulphide minerals and of identifying the phases by selective iridescent filming a study was made of the compounds of copper with arsenic, antimony, bismuth, and sulphur. The technique followed in this investigation was substantially the same as heretofore (1–4).

By way of refinement of technique there were added the following:

1. Chemical analyses of many of the synthetic products, to allow for sublimation losses.
2. Immersion of the bombs and thermo-couple in molten lead-tin alloy during heat treatment, to make the temperatures recorded by the thermo-couples more accurate.

The crystalline phases observed during this study were the following: chalcocite, covellite, famatinite, tetrahedrite, enargite, tennantite I, tennantite II, wittichenite I, wittichenite II, chalcostibite, klaprothite, cuprobismutite, stibnite, realgar, and bis-

muthinite. In addition arsenic-sulphur glasses were obtained whose composition is probably near that of orpiment.

The temperatures at which the phases solidified were appreciably higher than those at which sulpho-salts of silver solidify. This is perhaps one of the reasons for the more extensive solid-solution effects observed in the phases prepared in this investigation. As these temperatures of formation are much higher than the temperatures at which natural minerals precipitate from aqueous solution there is every likelihood that solid-solution effects in natural minerals are much less marked in the synthetic preparations with which this investigation is concerned. This prognostication is based, of course, on the well-accepted rule that mutual solubility in the solid state as well as in the liquid state decreases markedly with temperature. Some exceptions are known, but they are uncommon.

The solid solutions observed are believed to be of the substitutive type in which one atom of the crystal lattice is replaced by another atom rather than of the interstitial type in which disarrangement of the lattice is obtained. But the substituting atoms have commonly not been close relatives of the substituted atoms—a result we were not expecting to find, and one which is perhaps at the root of some of the marked effects on the filming rate of the phases.

SPECIAL PHENOMENA OBSERVED IN THIS STUDY.

Several peculiar filming phenomena have been noted some of which are perhaps special to the minerals under consideration and others seem to have general diagnostic possibilities. One of these concerns the appearance of definite end-colors; another, the sudden and automatic thickening of the film after completion of the filming; another, the anisotropy of the filmed surface; and still another, the index of refraction of the film.

On some phases an *end-color* has been observed; that is, past a certain filming time, the film ceases to grow. This is the case, for instance, in some specimens of chalcostibite and tetrahedrite. This phenomenon was investigated by changing the temperature

of the filming solution. The tests showed that at higher bath temperatures (40° C.) no film could be obtained on these minerals, but at a lower temperature (5° C.) the specimens displayed the normal sequence of interference colors without reaching an end-color. These results led to the formulation of an hypothesis: if film-formation is obtained from the joint operation of film-growth and film-resorption, an equilibrium could conceivably be

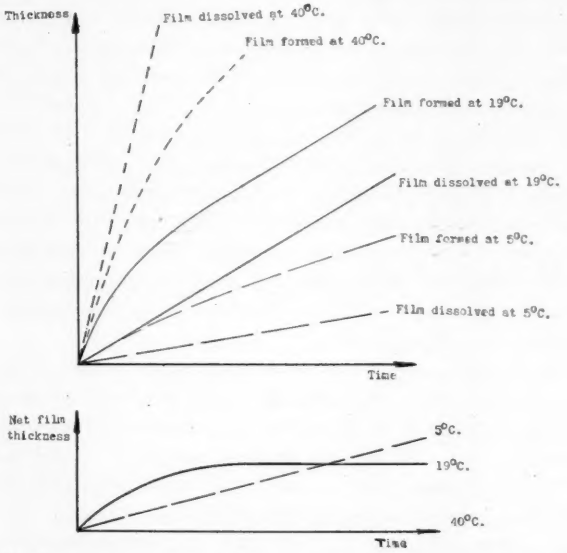


FIG. 1. Relationship between film formed and film dissolved in HCl-CrO_3 solution on chalcostibite as function of the bath temperature.

established between these tendencies under definite conditions of bath composition, temperature, and film thickness. The effect of bath temperature is probably not the same for film-growth and film-resorption; it would explain the change in filming behavior at different temperatures of the solution. Fig. 1 is an attempt to explain these conditions.

Another queer phenomenon consists in the *sudden increase in film thickness* after the specimen has been removed from the filming solution. This phenomenon has been observed on synthetic tetrahedrite of the fast-filming type described below, but not on natural tetrahedrite. The phenomenon is easy to observe under the microscope, as it proceeds slowly. Commonly, a few seconds to a few minutes after the end of the filming operation and starting from scratches and grain boundaries a spot appears that has a higher interference color than the parent film. The boundary between the growing spot and the rest of the surface is sharp. The spot grows sideways, at a rate of the order of magnitude of one tenth of a micron per second until all of the mineral has acquired the new color. The interference color of the changed film indicates that the optical thickness has been practically doubled. The index of refraction may have undergone alteration as the interference colors are changed not only in tint but also in intensity. This phenomenon could be due to the oxidation of the film substance. It was observed with air-immersion and oil-immersion objectives and does not seem to be especially photosensitive.

Since the intensity of the color observed on a filmed surface depends on the *index of refraction of the film*,[3] the combination of the appearance of the filmed surface viewed under oil and in air enables one to tell which phase is present, even if the filming rate of several phases is the same. This has been utilized in differentiating between several of the bismuth compounds.

Some of the films appear anisotropic but others are isotropic. In all cases considerable diagnostic value is likely to develop from this fact, especially since the anisotropic effects are incomparably more brilliant than those observed on unfilmed surfaces. The optics of the phenomenon will be discussed in a forthcoming article.[5]

FILMING SOLUTIONS.

The filming solutions already available yield satisfactory results for the identification and differentiation of all the phases. Brilliant interference colors were obtained especially in the copper-

antimony-sulphur and copper-bismuth-sulphur systems. Unfortunately these films cannot be shown to advantage in black-and-white photomicrographs.

The following filming solutions were used:

1. The standard chromium trioxide-hydrochloric acid solution whose composition is described elsewhere.[2] This solution yields the most striking interference colors, the usual times for immersion of the minerals into the bath ranging from 10 seconds to 5 minutes. The films obtained with this solution are not as durable as those of the standard chromium trioxide-sulphuric acid solution, which have been observed to retain their quality for several months but their durability is ample for a microscope study of an hour or two. In some cases the film obtained with the hydrochloric acid solution has a tendency to crystallize. This process is accelerated under the influence of heat (or light) and occurs, for instance, when the filmed mineral surface is illuminated under the microscope without daylight filter and at high magnification. The films are generally coherent and stick well to the mineral surface.

2. The standard chromium trioxide-sulphuric acid solution. Its preparation is as follows: 65 c.c. concentrated sulphuric acid are combined with an aqueous solution of 25.15 g. chromium trioxide and made up to a total volume of 1000 c.c. The usual filming times for the minerals range here from about 20 seconds to 10 minutes.

3. A 50–50 mixture of the two standard solutions was found effective in one instance. For the sake of brevity the standard chromium trioxide-hydrochloric acid solution will be termed "HCl–CrO_3 solution," the standard chromium trioxide-sulphuric acid solution "H_2SO_4–CrO_3 solution" and the mixture of the two, "combined solution." If not mentioned otherwise these solutions are used at room temperature which averaged 18–20° C.

PHOTOMICROGRAPHS.

A Bausch and Lomb metallographic microscope was used. The photomicrographs were taken with a Leica Model E which was

connected with the microscope by means of a "Micro-Ipso Attachment." The film used was the Kodak SS panchromatic daylight film. The exposure times ranged from ½ second to 40 seconds, according to the light intensity.

COPPER-ANTIMONY-SULPHUR-SYSTEM.

Mineralogists [6-8] recognize six phases in this system: two copper sulphides—covellite, CuS, and chalcocite, Cu_2S; two copper sulphoantimonites—chalcostibite (wolfsbergite), $Cu_2S \cdot Sb_2S_3$, and tetrahedrite, ranging from $3Cu_2S \cdot Sb_2S_3$ to $4Cu_2S \cdot Sb_2S_3$; one copper sulphoantimonate—famatinite, $3Cu_2S \cdot Sb_2S_5$; one antimony sulphide—stibnite, Sb_2S_3.

In addition to these phases, the existence of others is claimed by chemists and some mineralogists. Thus the compound, $3Cu_2S \cdot 2Sb_2S_3$, is said to have been synthesized by Rammelsberg.[10] Somerlad [11] prepared $Cu_2S \cdot 2Sb_2S_3$, which he calls "guejarite," but which Schneiderhoehn regards as a synonym for chalcostibite.[7] F. von Kobell [12] found in Copiapo, Chili, a complex mineral whose formula is supposed to be $3Cu_2S \cdot Sb_2S_3$ and which he terms stylotypite. According to Schneiderhöhn this mineral is a particular form of tetrahedrite and does not represent a special mineral species. The older syntheses were not followed by microscope study of the products. Their significance is, therefore, open to question.

An equilibrium diagram has been worked out by Parravano and de Cesaris [13] for the system Cu_2S–Sb_2S_3. This diagram includes two copper sulphoantimonites. The observations made in the present work verify the results of Parravano and de Cesaris, and in addition cover the synthesis of the copper sulphoantimonate.

Antimony sulphide or metallic antimony, metallic copper and sulphur were melted together, antimony sulphide being used at the antimony-end of the system because the formation of stibnite from the elements is not sufficiently exothermic to assure completion of the reaction; if metallic antimony is used directly, a considerable amount of metallic antimony is retained even in the presence of excess sulphur and the specimens are non-homo-

TABLE I.

SELECTED DESCRIPTIVE LIST OF SPECIMENS PREPARED IN THE COPPER-ANTIMONY-SULPHUR SYSTEM IN THE PRESENCE OF EXCESS SULPHUR.

Atomic Percentage of Metals		Phases	Structure	Heat Treatment*	Figure
Cu	Sb				
8.1	91.9	Stibnite Famatinite Sulphur	Idiomorphic crystals of stibnite in eutectic of stibnite and famatinite	*a*	2
22.5	77.5	Stibnite Famatinite Sulphur	Eutectic of famatinite and stibnite	*a*	4
34.4	65.6	Stibnite Famatinite Sulphur	Idiomorphic crystals of famatinite in stibnite-famatinite eutectic	*a*	3
44.8	55.2	Stibnite Famatinite Sulphur	Large crystals of famatinite in an eutectic of stibnite and famatinite	*a*	—
58.9	41.1	Famatinite Chalcostibite Stibnite Sulphur	Mostly famatinite in large dendrites. The matrix consists of stibnite-chalcostibite eutectic	*a*	7
69.6	30.4	Sulphur Famatinite Chalcostibite Tetrahedrite	Dendrites of famatinite in a ground mass of chalcostibite with interstitial tetrahedrite	*a*	8
72.3	27.7	Chalcocite Famatinite Tetrahedrite Chalcostibite Sulphur	Dendrites of chalcocite; famatinite as the second phase to crystallize, and also as the most abundant phase. Interstitial tetrahedrite and chalcostibite. If chalcocite is surrounded by the latter it has rims of famatinite directly around it	*a*	—
84.7	15.3	Chalcocite Covellite Famatinite Sulphur	Dendrites of chalcocite partly changed over to covellite in famatinite. Exsolution blobs of chalcocite in the famatinite	*a*	5
98.1	1.9	Chalcocite Covellite Famatinite Sulphur	Dendrites of chalcocite transformed partly to covellite in a groundmass of famatinite	*a*	—

* *a*—heated to 525° C. Cooled at normal furnace rate to 300° C., then quenched.

geneous. The antimony sulphide for the synthesis was prepared by repeated fusing of sulphur and antimony in an assay crucible.

In tables I and II the most characteristic specimens, the proportions of the constituents in each charge, the phases observed, the structures, the heat treatment used in preparation and the number of the photomicrographs are listed.

TABLE II.

SELECTED DESCRIPTIVE LIST OF SPECIMENS PREPARED IN THE COPPER-ANTIMONY-SULPHUR SYSTEM IN THE ABSENCE OF EXCESS SULPHUR.

Atomic Per Cent		Phases	Structure	Heat Treatment*	Photomicrograph
Cu	Sb				
34.4	65.6	Chalcostibite Stibnite Metal	Primary acicular crystals of chalcostibite in groundmass of stibnite; metal precipitated from chalcostibite	*a*	9
34.4	65.6	Famatinite Chalcostibite Stibnite	Elongated, idented crystals of famatinite in a groundmass of chalcostibite and stibnite	*a*	—
45.3	54.7	Chalcostibite Stibnite Tetrahedrite Metal	Groundmass of chalcostibite with high solid-solution effects, small rims of tetrahedrite. Metal precipitated from chalcostibite	*b*	—
58.9	41.1	Chalcostibite Tetrahedrite Famatinite	Primary tetrahedrite in eutectic-like structure with famatinite, surrounded by and included in chalcostibite	*a*	—
68.0	32.0	Tetrahedrite Chalcostibite Famatinite Chalcocite	Eutectic-like structure of famatinite and tetrahedrite. Small amount of chalcostibite and chalcocite	*b*	—

* *a*—Heated to 525° C. Cooled at normal furnace rate to 300° C., then quenched.
b—Heated to 580° C. Cooled at normal furnace rate to 350° C., then quenched.

A comparison of these two tables shows the great significance of the sulphur content of the specimens, affecting as it does the formation of phases and the structural relationship. Many specimens were obtained that lack the necessary sulphur content and display metal either in the form of ex-solution blebs from certain phases, or as large globules at the bottom of the sample. In these

cases the structures are characterized by striking solid-solution effects and by a lack of distinctive crystallization of the phases.

Discussion of Phases.

Six phases have been obtained that conform to the minerals covellite, chalcocite, chalcostibite, tetrahedrite, famatinite and stibnite. In most cases the phases could be distinguished in the unfilmed state by differences in shade and by behavior under polarized light. Where present in minute quantities and as fine intergrowths, however, definite differentiation required the use of selective iridescent filming.

For the identification of the specimens in this system the HCl–CrO_3 solution and the H_2SO_4–CrO_3 solution were used. Enormous variations in filming behavior of two of the phases (famatinite and tetrahedrite) were observed. These variations were so great, that for a time it seemed as if selective iridescent filming was worthless for the present investigation. However, further testing showed that the preparations responded in well-defined ways and that the extreme variation to which reference has just been made was due to the presence in solid solution of large quantities of impurities. The apparently erratic response of the phases to the filming baths could be utilized to classify the solid solutions that were obtained.

Tables X and XI are intended as an identification guide to the average filming behavior of the phases in typical preparations. Before this identification guide can be applied with assurance to unknown minerals it is necessary that extensive checks be made on natural minerals. It is believed that most natural minerals will react more slowly, since they must have formed at appreciably lower temperatures and are undoubtedly freer from solid-solution effects and especially of solid-solution effects of the type in which atomic replacement is by unrelated atoms.

Covellite. Synthetic covellite is deep blue and extremely anisotropic, just like natural covellite. Filming solutions give it colors that appear in unusual sequence because of selective light absorption by the mineral.[1]

Chalcocite.—Depending on its sulphur content chalcocite is gray to pale blue, the latter containing the most sulphur. Natural chalcocite may contain enough sulphur to represent 8 per cent dissolved covellite [7] and synthetic chalcocite may contain more than that amount.[14] Although chalcocite can dissolve considerable iron [14, 8] it does not seem to dissolve much more antimony than covellite since the covellitization of chalcocite has not resulted in a eutectoid of covellite and famatinite, as might otherwise have been expected. And from the uniformity in optical and filming characters of covellite that mineral seems especially free of solid-solution impurities.

Stibnite.—The characteristics of synthetic stibnite answer well to those of the natural mineral. Stibnite is very stable in its filming behavior. This may indicate that the tendency to form solid solution is inconsequential. It films only in HCl–CrO_3 solution (brilliant blue after 27–30 seconds) and displays beautiful interference colors.

Chalcostibite.—The characteristics of synthetic chalcostibite agree well with the descriptions of the natural mineral except that twinning was not observed. Chalcostibite films faster in the HCl–CrO_3 solution than in the H_2SO_4–CrO_3 solution. Solid-solution effects on chalcostibite have been observed at its contact with famatinite in specimens rich in sulphur. In this case chalcostibite probably takes some sulphur (perhaps also some copper) into solid solution, which causes a gradual increase in filming rate. This change in filming behavior is more marked if the filming is done in the H_2SO_4–CrO_3 solution.

Likewise the excrescence of blebs of metal from chalcostibite indicates that chalcostibite on freezing dissolves appreciably more metal than at lower temperatures, when the excess is precipitated from solution.

Tetrahedrite.—This phase is conspicuous by its variability in composition and filming behavior. Its appearance in the unfilmed state, however, is practically constant, red internal reflections being observed occasionally. The phase is always isotropic.

Famatinite.—Famatinite is characterized by its excellent anisotropism, its pleochroism and its pinkish color. The latter seems

to depend upon the sulphur content, sulphur-rich famatinite showing rose-violet colors, while the mineral in specimens poor in sulphur has a more grayish-white appearance. The filming rate of famatinite varies very much according to its solid-solution content: in the H_2SO_4–CrO_3 solution first-order blue is reached after from 20 seconds to 30 minutes, but normally after 5 minutes. Usually famatinite is not filmed by the HCl–CrO_3 solution but there are exceptions, especially with samples filming fast in the other solution.

Discussion of Structures.

Broadly speaking, the structures obtained can be classified into structures resulting from melts in the presence of excess sulphur, and those resulting from melts in the presence of the minimum of sulphur. Intermediate structures are also obtained. Furthermore, because of the consumption of sulphur by the bomb walls during cooling, the structure obtained may indicate a shift from excess to insufficiency of sulphur during the cooling.

In the presence of excess sulphur and considering successively melts having increasing copper content, the primary phases are first stibnite, then famatinite, then chalcocite. Stibnite and famatinite form an eutectic or eutectic-like mixture at about 8–9 per cent copper (Fig. 4). If the copper content is less than that, stibnite is the primary phase (Fig. 2); if the copper content is in excess of that amount famatinite is the primary phase (Fig. 3). If the proportion of copper exceeds that required to form famatinite, chalcocite is the primary phase. That is, there is no certainty of an eutectic of chalcocite and famatinite; the intergrowths of those phases that do occur look more as if the chalcocite precipitated from solid solution in the famatinite along directions crystallographically controlled by the latter (Fig. 5). In specimens containing chalcocite there has been a transformation of the chalcocite to covellite that is more or less complete. According to Lombard and Merwin[14] this transformation takes place at about 520° C. when sulphur is under its own vapor pressure. The transformation is sufficiently complete to indicate that the charges were in a pasty condition when it took place; that is, the fama-

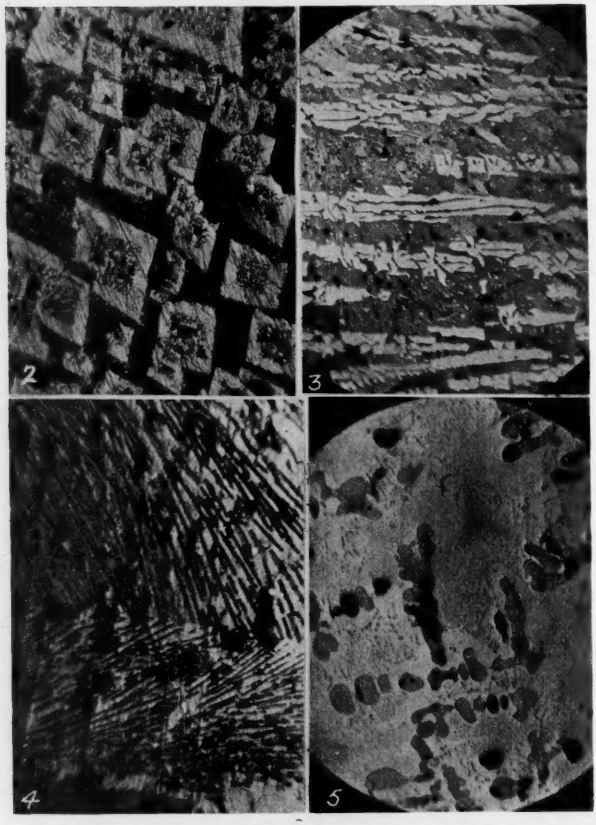


FIG. 2. Hollow dendrites of stibnite in eutectic of famatinite and stibnite. Filming time 23 seconds HCl–CrO_3 solution. Dendrites are basal sections and have filmed bright orange (white). Stibnite in groundmass has filmed dark blue (gray), and famatinite is white (white). × 270, oil.

FIG. 3. Indented crystals of famatinite in a groundmass of fine stibnite-famatinite eutectic; at this magnification the eutectic is not resolved and appears gray. Filming time 25 seconds HCl–CrO_3 solution. Colors: substantially as above. × 60.

tinite-stibnite eutectic occurs at a temperature lower than the chalcocite-covellite transformation.

In the presence of just enough sulphur to form compounds in the $Cu_2S \cdot Sb_2S_3$ series, and considering successively melts having increasing copper content, the primary phases are first stibnite then chalcostibite, tetrahedrite and chalcocite. Stibnite and chalcostibite form an eutectic but chalcostibite and tetrahedrite both decompose before melting (incongruent melting points). That is, the structures are substantially what would be expected from the data of Parravano and de Cesaris.[13]

In the presence of intermediate quantities of sulphur, intergrowths of famatinite with tetrahedrite (Fig. 6), of famatinite with chalcostibite and stibnite (Fig. 7), of famatinite with tetrahedrite and chalcostibite (Fig. 8), and of all four phases are obtained. There is no indication of the formation of a ternary eutectic. Also, since the sulphur content of the bombs is being steadily reduced by consumption of the vapor by the bomb walls, specimens of intermediate sulphur content always show famatinite as the first phase to freeze. Whether the opposite would occur if the sulphur content were to go increasing cannot be answered.

In specimens high in sulphur tetrahedrite occurs occasionally as small specks in famatinite or chalcostibite. The appearance of the two copper sulphoantimonites in the presence of excess sulphur is due to heterogeneity of the melt, the sulphur vapor having apparently not come in sufficiently close contact with the constituents.

The change from famatinite to tetrahedrite caused by a decrease in sulphur content of the charge (reaction of sulphur with the iron of the bomb) has often been observed. In that case the composition of the tetrahedrite varies gradually up to the fama-

FIG. 4. Famatinite-stibnite eutectic. Filming time 23 seconds HCl–CrO_3 solution. Colors: stibnite, dark blue (gray); famatinite, white (white). × 1100, oil; oblique illumination.

FIG. 5. Chalcocite dendrites in a groundmass of famatinite from which chalcocite has precipitated in the solid state as small oriented blebs. Filming time 90 seconds HCl–CrO_3 solution. Colors: chalcocite, blue; famatinite, white. × 60.

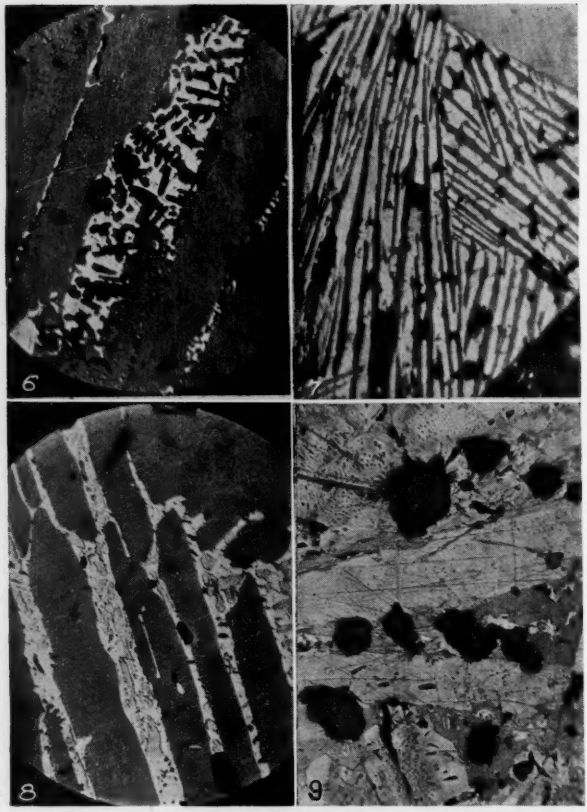


FIG. 6. Famatinite in large crystals (containing ex-solution chalcocite) that occlude eutectic-like intergrowth of famatinite and tetrahedrite. Filming time 20 seconds H_2SO_4–CrO_3 solution. Colors: famatinite, orange-brown I (gray); tetrahedrite, pale tan I (white); chalcocite, blue (light gray). × 60.

FIG. 7. Eutectic of stibnite and chalcostibite in between large crystals of famatinite. Filming time 35 seconds HCl–CrO_3 solution. Colors: famatinite, orange I (gray); chalcostibite, yellow I (gray); stibnite, pale blue I (white). × 180.

tinite boundary; and the composition of the famatinite varies gradually from the tetrahedrite boundary to the core. These variations are clearly seen on filming. They indicate partial solubility of famatinite in tetrahedrite, and conversely partial solubility of tetrahedrite in famatinite; complete miscibility is excluded.

In specimens low in sulphur tetrahedrite seems to precipitate famatinite in small round specks during the process of solidification. This indicates decreasing solubility of famatinite in tetrahedrite with reduction in temperature.

If the quantity of sulphur is insufficient for compounds of Cu_2S with Sb_2S_3, excess metal appears as ex-solution blebs, particularly in the chalcostibite (Fig. 9) and in tetrahedrite. This indicates that the solubility of the metal in chalcostibite and tetrahedrite decreases with decreasing temperature.

Solid-Solution Effects

An attempt was made to determine the extent to which solid solution appears in famatinite, tetrahedrite and chalcostibite, and to correlate the composition of these various solid solutions. To that end a number of special melts were prepared giving larger samples than usual, one set of specimens having approximately the chalcostibite composition and two other sets having approximately the tetrahedrite-famatinite composition (insofar as the metals are concerned). Within each series the sulphur was varied. The specimens were cut in two vertically, one-half being analyzed for antimony, copper and sulphur and the other half being polished. A count was made of the abundance of each

FIG. 8. Large crystals of famatinite enclosing chalcostibite with interstitial tetrahedrite. Filming time 4 minutes H_2SO_4–CrO_3 solution. Colors: famatinite, violet I (gray); chalcostibite, yellow II (white); tetrahedrite, blue I (pale gray). × 60.

FIG. 9. Chalcostibite as elongated crystals in a groundmass of chalcostibite and stibnite. Metal precipitated from chalcostibite appears as pits. Large dark areas are holes. Filming time 30 seconds HCl–CrO_3 solution. Colors: Chalcostibite, yellow I (pale gray); stibnite, blue I (medium gray); metal etched, (dark gray). × 80.

phase in the polished sections and a note was made of the general filming behavior. These results are presented in Table III.

The filming of famatinite falls in three classes: *A*. Very fast-filming famatinite occurring in association with chalcostibite; *B*. "Normal"-filming famatinite in specimens high in sulphur; *C*. Slow-filming famatinite occurring in association with chalcocite and covellite.

TABLE III.

LIST OF SPECIMENS PREPARED IN THE COPPER-ANTIMONY-SULPHUR SYSTEM CHEMICAL AND MICROSCOPE ANALYSIS.

No. of Specimen	Chemical Analysis in Weight Per Cent			Microscope Analysis in Weight Per Cent											
	Cu %	Sb %	S %	Chalcocite	Covellite	Famatinite			Tetrahedrite			Chalcostibite	Stibnite	Metal
						A	B	C	A	B	C			
2	48.75	26.76	24.89	3.4				2.2	89.9			4.5		
3	46.81	25.62	27.83	0.7	5.0			51.6			42.7			
4	48.80	26.76	24.26	1.0				15.0			84.0			
5	47.20	26.02	26.49	2.7				34.0			63.3			
6	46.17	25.14	28.43		0.8			91.6			7.6			
7	46.59	25.58	27.61	0.4	0.7			66.8			32.1			
8	46.32	25.23	28.47	0.3	2.0			86.5			11.2			
10	40.89	35.73	24.44							88.4		10.4		1.2
12	39.22	36.00	25.05							76.9		23.1		
13	42.48	33.07	24.51							78.9		21.1		
14	41.85	33.18	24.99							89.8		10.2		
15	42.42	33.02	24.68							95.2		4.8		
16	40.77	31.71	27.79			54.5			40.0			5.5		
17	40.19	31.22	28.54			72.5			19.5			8.0		
18	37.81	34.27	28.49			55.7			9.3			35.0		
19	22.43	52.99	24.97									93.5	5.3	1.2
20	22.19	53.52	24.47							0.1		96.4	2.7	0.8
21	21.50	53.21	26.05							0.1		94.2	5.7	
22	22.06	51.44	26.93							0.5		95.2	4.3	
23	22.02	51.42	26.91							0.1		90.9	9.0	
24	22.08	51.10	27.13				2.4					75.1	22.5	
25	21.74	49.14	29.39				37.6					4.2	58.2	
26	22.02	48.84	29.36				40.2					1.3	58.5	
27	20.91	49.89	29.50				40.3					0.4	59.3	

Likewise three varieties of tetrahedrite can be recognized: *A*. Fast-filming tetrahedrite associated with famatinite and chalcostibite; *B*. Medium-filming tetrahedrite associated with chalcostibite only; *C*. Slow-filming tetrahedrite associated with chalcocite.

The chalcostibite shows variations in filming rate that are much less extreme, yet more marked than those of stibnite.

By grouping those specimens in which the minerals behaved in like manner and by setting up simultaneous equations relating microscope assay to chemical assay it was possible to determine the composition of the solid solutions involved. The determinations are approximations only as they involved the following assumptions: that chalcocite contains excess sulphur in solid solution (23 per cent S) and that stibnite and covellite are c.p.

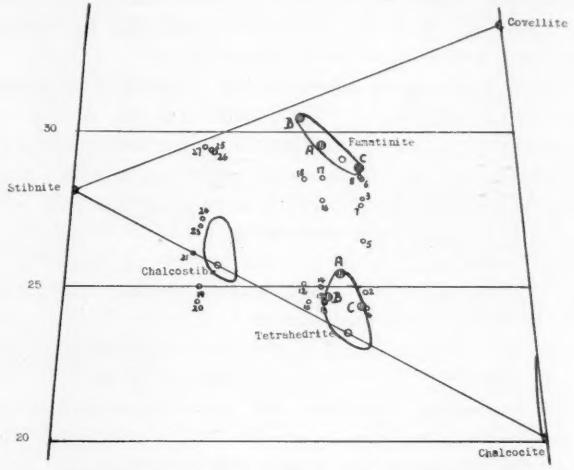


FIG. 10. Diagram showing compositions of solid solutions synthesized in the Cu–Sb–S system (sulphur scale enlarged).

phases. In spite of the approximate character of the conclusions it seems reasonable to believe that the data obtained are valid in their broader aspects. Fig. 10 shows the results obtained. In it appear the experimental points (indicated by numerals) and the delineated areas of solid solution of each phase. The letters in caps refer to the varieties of famatinite and stibnite which are discussed above. It should be noted that the vertical or sulphur scale in Fig. 10 is enlarged five fold.

COPPER-ARSENIC-SULPHUR SYSTEM.

Because of the bivalency of arsenic and copper this system can no more be treated as a binary than the copper-antimony-sulphur system. A comprehensive study of the system is not be found in the literature and the present work is not complete because the viscosity of the melt near the arsenic sulphide-end of the system prevents crystallization. Away from the arsenic sulphide-end, however, good specimens were obtained. Attempts were made to fuse the specimens in an atmosphere of a sulphur-solvent (carbon disulphide; benzene) in a high pressure bomb in order to decrease the viscosity of the melt and to approach hydrothermal conditions. The results were not satisfactory.

Besides the two copper sulphides, four compounds are generally recognized by mineralogists: two arsenic sulphides, realgar, AsS, and orpiment, As_2S_3; one sulpharsenite, tennantite (julianite), $3Cu_2S \cdot As_2S_3$; and one sulpharsenate, enargite (luzonite), $3Cu_2S \cdot As_2S_5$. Schneiderhöhn describes a mineral, lautite, as a definite mineral species having the composition CuAsS. Weisbach considers it, according to Mellor,[15] as a mixture of tennantite and arsenic. Murdoch regards it as a mixture of enargite and arsenic and Orcel thinks it is merely enargite.[7]

Many compounds belonging to this system are described in the literature especially by Somerlad[11] who synthesized Cu–As–S minerals by chemical methods. But this work is open to question because the preparations were not studied microscopically.

A reinvestigation of the system was undertaken by melting together arsenic, copper and sulphur. Tables IV and V contain descriptions of characteristic specimens. The listed proportions of copper to arsenic are probably inaccurate because of reaction of the arsenic and sulphur vapors with the iron of the bombs to form arsenopyrite and because of sublimation of elemental arsenic. Series of specimens have been analyzed chemically to calculate the composition of the constituents. A comparison between the compositions of the charges and the composition as found by chemical analyses of the specimens shows that the loss is highest in those specimens high in arsenic and low

TABLE IV.

CHARACTERISTIC SPECIMENS PREPARED IN THE COPPER-ARSENIC-SULPHUR SYSTEM IN THE PRESENCE OF EXCESS SULPHUR.

Atomic Per Cent		Phases	Structure	Heat Treatment*	Photomicrograph
Cu	As				
91.5	8.5	Chalcocite Covellite Enargite Sulphur	Dendrites of chalcocite partly changed over to covellite in a groundmass of enargite	*a*	—
82.6	17.4	Chalcocite Covellite Enargite Sulphur	Chalcocite, partly as primary dendrites, partly as eutectic with enargite, and partly precipitated from enargite. Some chalcocite changed over to covellite	*a*	15
63.5	36.5	Chalcocite Covellite Enargite Sulphur	Idiomorphic enargite, eutectic of chalcocite and enargite. Chalcocite partly changed over to covellite	*b*	14
53.8	46.2	Enargite As-S glass Tennantite Sulphur	Very uniform large crystals of enargite with small veins of As-S glass; in the latter small crystals of tennantite	*a*	—
43.8	56.2	Enargite As-S glass Tennantite Sulphur	Large idiomorphic crystals of enargite in a matrix of vitreous arsenic sulphide with rosettes of tennantite	*a*	—
33.4	66.6	Enargite Arsenic sulphide Tennantite Sulphur	Idiomorphic crystals of enargite in a vitreous mass of arsenic sulphide, which contains rosettes of tennantite	*a*	—
22.5	77.5	Enargite Arsenic sulphide Tennantite Sulphur	Primary enargite in a matrix of arsenic sulphide glass that contains crystals of tennantite	*a*	16

* *a*—Heated to 550° C. Cooled at normal furnace rate to 200° C., then quenched.
b—Heated to 680° C. Cooled at normal furnace rate to 200° C., then quenched.

in sulphur and that it averages around .4 per cent by weight.

For the identification of the phases the HCl–CrO_3 and H_2SO_4–CrO_3 solutions were used and gave satisfactory results. The comprehensive identification guide (Tables X and XI) at the end of this report records the filming results with these solutions. It is intended for use as explained in conjunction with the copper-antimony-sulphur system.

TABLE V.

CHARACTERISTIC SPECIMENS PREPARED IN THE COPPER-ARSENIC-SULPHUR SYSTEM IN THE ABSENCE OF EXCESS SULPHUR.

Atomic Per Cent		Phases	Structure	Heat Treatment*	Photomicrograph
Cu	As				
82.6	17.4	Enargite Tennantite I Tennantite II	Large crystals of enargite and tennantite I in intergrowth. The tennantite contains a small amount of tennantite II	*b*	18
63.5	36.5	Tennantite I Metal	Tennantite I with high solid-solution effects, not well crystallized, with ex-solution metal	*b*	—
53.8	46.2	Tennantite I Tennantite II As-S glass Realgar	Tennantite I showing high solid-solution effects with tennantite II as idiomorphic crystals, some As-S glass with crystallized realgar	*c*	13
43.8	56.2	Arsenic sulphide Enargite Tennantite II	Crystals of enargite and tennantite II in a matrix of As-S glass	*c*	—
33.4	66.6	Tennantite As-S glass Orpiment (?)	Primary tennantite II in a groundmass of vitreous As-S from which globules of another As-S glass have segregated	*c*	12
22.5	77.5	Tennantite As-S glass Realgar	As-S glass with crystallized realgar in a groundmass of tennantite I showing high solid-solution effects	*d*	11
22.5	77.5	Tennantite Enargite As-S glass	Rounded crystals of enargite and rosettes and elongated crystals of tennantite I in a matrix of As-S glass	*d*	17

* *b*—Heated to 680° C. Cooled at normal furnace rate to 300° C., then quenched.
c—Heated to 600° C. Cooled at normal furnace rate to 200° C., then quenched.
d—Heated to 575° C. Cooled at normal furnace rate to 200° C., then quenched.

Discussion of Phases.

Chalcocite and covellite have already been described. Their appearance and filming behavior in this system are essentially the same as in the copper-antimony-sulphur system.

Arsenic sulphide occurs in specimens high in sulphur in the form of a vitreous mass with red internal reflections. Its com-

position seems to be changeable. In the specimens low in sulphur a phase occurring in needle-like crystals has segregated from this glass. These crystals show orange-yellow internal reflections and probably have the composition of realgar (Fig. 11). They are very soft and film in H_2SO_4–CrO_3 solution considerably faster than does the groundmass from which they have crystallized. Specimens of intermediate sulphur content sometimes contain in the vitreous arsenic-sulphide mass rounded globules of a second glass, which shows lemon-yellow internal reflection and whose filming rate is about that of realgar (Fig 12). These are probably close to orpiment in their composition as can be concluded from their occurrence and the character of their internal reflection. According to Mellor [15] orpiment can be transformed easily into a "red vitreous mass." Perhaps the arsenic-sulphide glass that occurs in specimens of intermediate and high sulphur content also has the composition of orpiment. It seems, however, that this glass usually contains more sulphur than is indicated by the formula As_2S_3. That glass after 5 minutes in H_2SO_4–CrO_3 solution acquires a grayish-blue color. The staining rate in the HCl–CrO_3 solution is practically the same.

Well-crystallized orpiment of the golden-yellow color typical of the natural mineral was obtained only in minute crystals on the surface of some specimens. This suggests that crystalline orpiment can be synthesized if arsenic and sulphur are combined when both are in the vapor state.

Tennantite occurs in the system in two well-differentiated forms. Tennantite I occurs only in specimens of intermediate and low sulphur content. It has a grayish-white color, is isotropic and films in the HCl–CrO_3 and H_2SO_4–CrO_3 solutions. It seems to have a noticeable tendency to form solid solution judging from the gradation in interference color and from the change in filming rate as observed in different specimens.

Tennantite II is, in its natural color, slightly darker than form I. It occurs only in the specimens with excess sulphur and in comparatively small quantities. It films considerably faster than the other tennantite and displays pure and beautiful interference

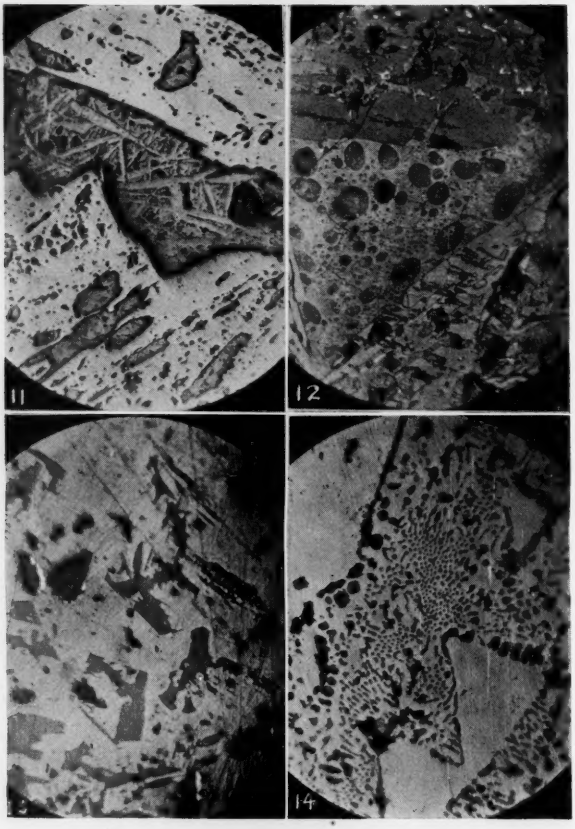


FIG. 11. Primary tennantite (white) with As–S glass (gray) from which realgar needles have crystallized; not filmed. × 60.

FIG. 12. Partly resorbed tennantite crystals in a matrix of As–S glass from which globules of a second glass have segregated. Filming time, 2 minutes HCl–CrO_3 solution. Colors: tennantite, blue of various shades (crystal-orientation effect); groundmass-glass, brown; dispersed glass, violet. × 130, oil.

FIG. 13. Two varieties or two species of tennantite: tennantite II (medium gray) in idiomorphic crystals in a groundmass of tennantite I.

colors. It crystallizes mostly in elongated and often in rosette-shaped crystals.

Both forms of tennantite correspond closely in their physical properties to the natural mineral as described by different authors. Internal reflection was not observed.

Tennantite I found in the specimens low in sulphur occurs as a primary phase in compact crystals, also in intergrowth with tennantite II. Its tendency to undergo solid solution has already been discussed. In specimens lacking the necessary sulphur content it precipitates metal in fine drops. This form of tennantite is probably the typical " fahlerz " species with its wide range of possible compositions.

According to its filming behavior *tennantite II* seems more definite in composition. It occurs in eutectic-like intergrowth with enargite and in elongated crystals and typical iron-cross shaped forms as a secondary phase after the formation of enargite in a matrix of the arsenic-sulphide glass. Its appearance is very similar to that of tetrahedrite as found in specimens high in sulphur.

In some cases both forms of tennantite were present in the same specimen (Fig. 13), tennantite II occurring as idiomorphic crystals in a groundmass of tennantite I whose filming rate increases in contact with form II. No adequate explanation can be offered. It is possible of course that forms I and II are allotropic forms or that further study will show that they grade into each other.

Enargite and luzonite having both the same chemical composition are, according to Schneiderhöhn [7] and Klockmann,[8] two different mineral species: The latter is not rhombic, shows no cleavage and has a typical twinning structure. In this investi-

Dark gray off-focus areas are arsenic-sulphur glass. Filming time 3 minutes HCl–CrO_3 solution. Colors: tennantite I, orange (I); tennantite II, blue (I). × 130, oil.

FIG. 14. Dendrites of enargite in chalcocite-enargite eutectic. Filming time 90 seconds HCl–CrO_3 solution. Colors: chalcocite, blue; enargite, white. × 130, oil.

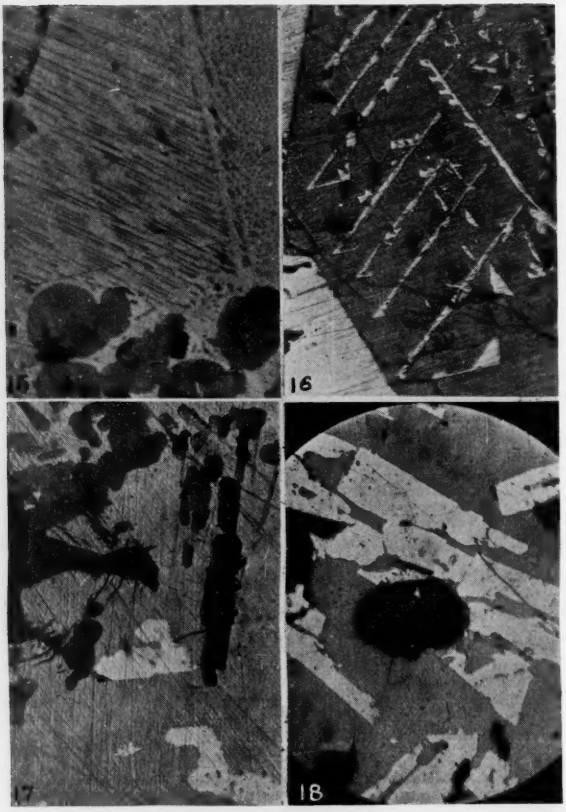


FIG. 15. Dendrites of chalcocite and ex-solution chalcocite in enargite; unfilmed. Colors: chalcocite, pale blue; enargite, white. × 250, oil.

FIG. 16. Crystals of tennantite in "fish-hook" habit in groundmass of arsenic-sulphur glass; portion of large enargite dendrite in left corner. Filming time 2 minutes HCl–CrO_3 solution. Colors: tennantite, purple I to orange I according to crystal orientation (white to dark gray); enargite, white, glass, brown I (gray). × 120, oil.

FIG. 17. Resorbed enargite crystals in matrix of As–S glass from which tennantite also has grown and been partly resorbed. Filming time

gation of the copper-arsenic-sulphur system no phase has been found whose properties would correspond to the description of luzonite. Enargite has a steel-gray color and is characterized by its perfect cleavage and its strong anisotropism. It is not as pleochroic as famatinite. It does not film in either one of the solutions, this being a good means of distinction from the other phases in the system. Attempts to obtain a good film with other filming solutions did not yield satisfactory results. Thus no study of solid-solution effects based on iridescent filming could be made on enargite.

Discussion of Structures.

As in the case of the copper-antimony-sulphur system two general groups of structures have been obtained, one corresponding to the presence of excess sulphur, and the other to deficiency in sulphur.

In the presence of excess sulphur and starting with specimens having the most copper the primary phases are chalcocite, then enargite. A chalcocite-enargite eutectic is formed as may be seen from Fig. 14, which shows dendrites of enargite in a chalcocite-enargite eutectic.

Ex-solution precipitation of chalcocite in enargite also occurs (Fig. 15), resembling samples of enargite from Butte in which minute inclusions of chalcocite and bornite are to be seen. In those samples, however, the inclusions are much finer than in the synthetic products, the average size being of the order of magnitude of 0.5–1.0 micron. No eutectic of enargite with any arsenic sulphide has been observed, the enargite always crystallized first in well-formed crystals (Fig. 16), although somewhat resorbed if the composition of the glass changed during cooling with reduction in sulphur content (Fig. 17).

---

3 minutes HCl–CrO_3 solution. Colors: tennantite, violet-blue I (dark gray); enargite, white; glass, brown I. × 120, oil.

FIG. 18. Primary enargite crystals in tennantite. Filming time 2 minutes HCl–CrO_3 solution. Colors: enargite, white; tennantite, blue I (light gray); holes, black. × 60.

If a deficiency in sulphur prevails, the sequence of primary phases, starting from the high-copper end of the series is chalcocite, tennantite I. No chalcocite-tennantite eutectic has been observed. It is therefore concluded that tennantite has an incongruent melting point. No tennantite-arsenic sulphide eutectic has been observed. In specimens of intermediate sulphur content, enargite has always appeared primary to tennantite (Fig. 18). Associations of enargite, tennantite and arsenic-sulphide glasses have been observed very commonly.

As in the case of the copper-antimony-sulphur system a number of specimens were prepared on which both chemical and micro-

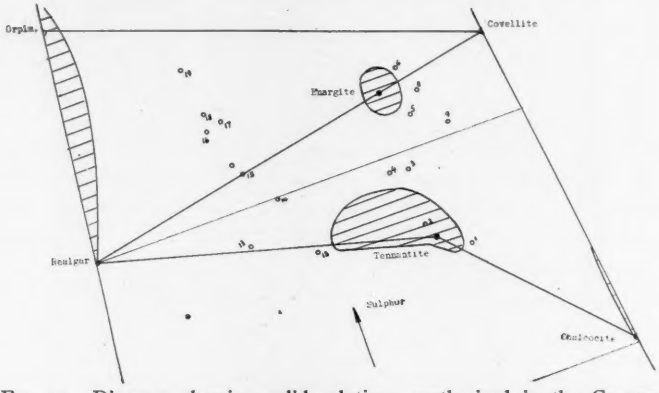


FIG. 19. Diagram showing solid solutions synthesized in the Copper-Arsenic-Sulphur system (sulphur scale enlarged).

scope analyses were made. The results are summarized in Fig. 19. Broadly speaking there is a marked parallel between the two systems with the following differences: that enargite is more definite than famatinite, that tennantite is more variable than tetrahedrite, and that the identity of the arsenic sulphide is in considerable doubt.

ANTIMONY-ARSENIC-SULPHUR SYSTEM.

A brief investigation of this system was made to inquire into the possible solid-solution effects between antimony sulphide and

arsenic sulphide, and to make sure that no compounds besides the end-members of the system are formed.*

A series of specimens were prepared in the presence of excess sulphur by fusing together antimony or antimony sulphide, arsenic and sulphur. Table VI is a list of typical specimens. All specimens are characterized by a tendency to stratify into layers according to specific gravities.

TABLE VI.

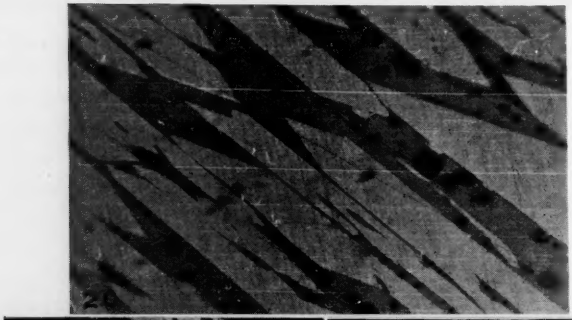
CHARACTERISTIC SPECIMENS PREPARED IN THE ANTIMONY-ARSENIC-SULPHUR SYSTEM IN THE PRESENCE OF EXCESS SULPHUR.

Atomic Per Cent		Phases	Structure	Heat Treatment*	Photomicrograph
Sb	As				
84.7	15.3	Stibnite Arsenic sulphide Sulphur	Idiomorphic stibnite as dendrites and needles in a matrix of arsenic-sulphide glass	*a*	21
71.0	29.0	Stibnite Arsenic sulphide Orpiment (?) Sulphur	Stibnite as dendrites in a groundmass of As-S glass from which globules of another As-S glass (orpiment (?)) have segregated	*a*	20
48.0	52.0	Stibnite As-S glass Realgar Sulphur	Stibnite dendrites in an arsenic-sulphide glass. Needles of realgar are segregated from the latter	*a*	—
20.8	79.2	Stibnite As-S glass Realgar Orpiment (?)	Specimen segregated into three layers, bottom part As-S glass with globules of orpiment (?), middle layer: stibnite in As-S glass, top layer: glass with realgar crystals and few stibnite needles	*a*	—
13.3	86.7	Stibnite As-S glass Orpiment (?) Realgar	Structure as above; small amount of stibnite in long, thin needles	*a*	22

* *a*—Heated to 530° C. Cooled at normal furnace rate to 250° C., then quenched.

No intermediate compound was observed. A eutectic-like structure between stibnite and arsenic sulphide occurs especially

* The existence of antimony arsenites and arsenates, claimed by Berzelius, is very uncertain.[15]



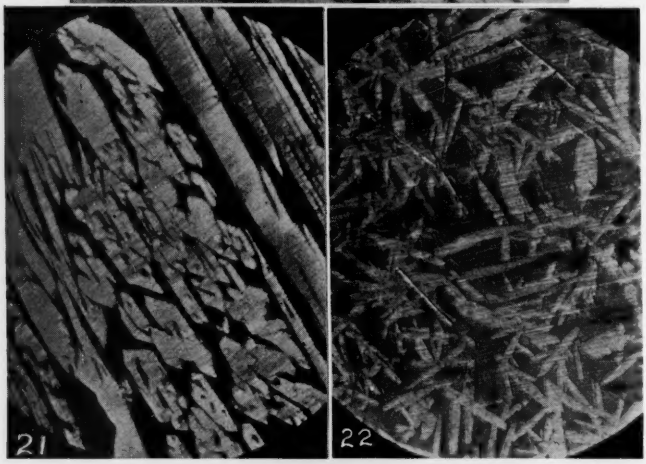


FIG. 20. Dendrites of stibnite (white) in As–S glass from which globules of a second glass phase (orpiment?) have segregated; unfilmed. × 650, oil.

FIG. 21. Dendrites and elongated crystals of stibnite (white) in As–S glass; unfilmed. × 70, oil.

FIG. 22. Three long, thin needles of stibnite (white) in As–S glass (gray), from which realgar (light gray) has crystallized; unfilmed. × 70, oil.

in specimens at the antimony-end of the system. Stibnite seems, however, to be always primary because arsenic sulphide never occurs as a truly idiomorphic phase. The eutectic-like structure,

as shown in some photomicrographs, represents, therefore, merely the occurrence of stibnite dendrites in a matrix of arsenic-sulphide glass. Crystallized realgar and vitreous globules of the probable composition of orpiment as segregated from the As–S glass are common, especially at the arsenic-end of the system.

The solid solubility of stibnite in arsenic-sulphide glass is apparently very high (up to 15 per cent) as can be concluded from the non-appearance of stibnite in the specimens high in arsenic.

A slight solubility of arsenic in stibnite seems to exist as can be inferred from the decrease in filming rate of stibnite in specimens high in arsenic.

RELATIONSHIP BETWEEN FAMATINITE AND ENARGITE.

It is commonly accepted by mineralogists that almost perfect miscibility exists between tetrahedrite and tennantite. The relationship between famatinite and enargite, however, is still uncertain, and the opinions of different authors diverge concerning the existence of a mixed-crystal range between these two components in the form of luzonite and stibioluzonite, as described, for instance, by Schneiderhöhn and Ramdohr.[7]

The essential optical differences between enargite on the one hand and luzonite and stibioluzonite on the other hand consist, according to Schneiderhöhn and Ramdohr, in the difference in crystal system; but there are also the lack of cleavage, the typical twinning structure and the more pinkish color of the last two species. Enargite and famatinite are commonly believed to be only slightly soluble in each other.

It seemed, therefore, of interest to investigate the relationship of these two phases by preparing specimens in the pseudoternary system copper-antimony-arsenic-sulphur. The three boundary systems have already been discussed in this report. In Table VII the most characteristic specimens, the phases and structures observed and the heat treatment of each specimen are listed. From this table it can be seen that the phases in this system correspond to those already described in the discussion of the boundary systems.

TABLE VII.

SELECTED LIST OF SPECIMENS PREPARED IN THE COPPER-ANTIMONY-ARSENIC-SULPHUR SYSTEM IN THE PRESENCE OF EXCESS SULPHUR CHARACTERISTIC FOR THE RELATIONSHIP BETWEEN FAMATINITE AND ENARGITE.

Atomic Per Cent			Phases	Structure	Heat Treatment*	Photomicrograph
Cu	Sb	As				
14.9	46.9	35.2	Famatinite Enargite Chalcostibite Stibnite As-S glass	Primary famatinite, some indented crystals of enargite, idiomorphic chalcostibite in a matrix of stibnite and arsenic-sulphide glass. No twinning on famatinite	*a*	—
12.4	13.3	74.3	Enargite Famatinite Tennantite As-S glass	The arsenic-sulphide glass is in abundance with enargite in small quantities, large amount of famatinite without twinning. Rosettes of tennantite	*a*	—
30.6	56.2	13.2	Famatinite Chalcostibite Stibnite As-S glass	Elongated, idiomorphic crystals of famatinite without twinning and needles of chalcostibite in a groundmass of stibnite and arsenic-sulphide glass	*b*	—
27.8	36.5	35.7	Famatinite Enargite Chalcostibite Stibnite Tennantite As-S glass	In an abundant matrix of As-S glass which must contain much antimony in solid solution, indented crystals of famatinite (twinned), small amount of enargite and tennantite, and needles of chalcostibite and stibnite	*b*	—
24.5	12.8	62.7	Enargite Famatinite Tennantite As-S glass	Indented and twinned crystals of famatinite and relatively small amount of enargite, some tennantite rosettes in As-S glass	*b*	—
40.8	35.7	23.5	Famatinite Enargite Tetrahedrite-tennantite Chalcostibite Stibnite As-S glass	Primary famatinite (not twinned), enargite, rosettes of tennantite-tetrahedrite, needles of chalcostibite in a groundmass of As-S glass-stibnite	*b*	—
34.8	6.1	59.1	Enargite Famatinite Tennantite-tetrahedrite As-S glass	Primary enargite, famatinite slightly twinned and tennantite-tetrahedrite in rosettes in a vitreous As-S groundmass	*b*	25

* *a*—Heated to 500° C. Cooled at normal furnace rate to 250° C., then quenched.
b—Heated to 600° C. Cooled at normal furnace rate to 300° C., then quenched.

TABLE VII (*Continued*).

Atomic Per Cent			Phases	Structure	Heat Treatment*	Photomicrograph
Cu	Sb	As				
51.2	26.8	22.0	Famatinite Enargite Tetrahedrite Chalcostibite Stibnite As-S glass	Elongated crystals of primary famatinite (not twinned), some enargite and tetrahedrite, needles of chalcostibite in a matrix of stibnite and As-S glass	*c*	—
48.2	12.2	39.6	Enargite Famatinite Tetrahedrite-tennantite Chalcostibite As-S glass Realgar	Primary enargite sometimes in eutectic-like structure with famatinite, rosettes and compact crystals of tetrahedrite-tennantite with chalcostibite in a groundmass of As-S glass with segregated realgar	*c*	—
58.0	12.2	29.8	Enargite Tetrahedrite-tennantite Chalcostibite As-S glass	Primary enargite in abundance, small amount of tetrahedrite-tennantite rosettes, needles of chalcostibite in a matrix of As-S glass	*c*	—
69.8	15.2	15.0	Famatinite Tetrahedrite-tennantite Chalcostibite As-S glass	Primary famatinite, not twinned, tetrahedrite-tennantite in compact crystals, chalcostibite needles in a relatively small amount of As-S glass	*c*	—
65.9	5.7	28.4	Enargite Famatinite Tetrahedrite-tennantite Chalcostibite As-S glass	Primary enargite, famatinite (twinned) in large crystals, rosettes of tennantite, tetrahedrite, needles of chalcostibite in a matrix of As-S glass	*c*	24
78.5	11.9	9.6	Chalcocite Famatinite Tetrahedrite-tennantite Chalcostibite	Primary chalcocite dendrites, famatinite (untwinned) with high solid-solution effects, in a groundmass consisting of tetrahedrite-tennantite and chalcostibite	*c*	—
74.3	2.8	22.9	Chalcocite Covellite Enargite Famatinite	Chalcocite primary and precipitated from enargite. Chalcocite partly changed over to covellite. Small rims and ribbons of famatinite with high solid-solution effects	*c*	—

c—Heated to 600° C. Cooled at normal furnace rate to 150° C., then quenched.

Phase Relationship.

Special attention was paid to the change in properties and to the occurrence of famatinite and enargite. Famatinite can be differentiated from enargite by its pleochroism, pinkish color, lack of perfect cleavage and its staining behavior. In some cases famatinite shows beautiful twinning, which led first to the conclusion that it was luzonite or stibioluzonite. This question can only be solved definitely by means of calculations of the phase composition. This, however, is rendered difficult by the fact that the actual composition of tetrahedrite and tennantite is unknown, and that the high solid solubility of antimony in the arsenic-sulphide glass as well as the variation in the composition of this glass complicates the conditions considerably. Thus, only approximate calculations of the phase composition could be made. These led to the following conclusions:

Famatinite has a comparatively high tendency to take arsenic into solid solution. This is concluded after the calculation of its probable composition, from the grading in film thickness in contact with arsenic sulphide and from its decrease in filming rate at the arsenic sulphide-side of the system. With arsenic in solid solution it seems to have a tendency to become twinned, a structure which has never been observed on famatinite devoid of arsenic. This twinning was observed especially in specimens in which the crystallization of famatinite had to overcome obstacles either in form of primary enargite or in the form of a highly viscous melt.

Enargite can take an appreciable quantity of antimony into solid solution. The cleavage, found to be a significant property of enargite in the copper-arsenic-sulphur system, has also been observed in the compound system but is not as typical as with enargite not containing antimony. Antimonial enargite retains the steel-gray color of antimony-free enargite and can, therefore, not be mistaken for famatinite. The filming behavior of antimonial enargite differs from that of pure enargite: a film could be obtained on this form of enargite with both filming solutions but a film cannot be obtained on pure enargite. The filming

rate is similar to that of pure famatinite. It is of interest to note in this connection that natural enargite from Butte, Montana, which is antimony-free cannot be filmed while the enargite from Bor, Yugoslavia, which shows replacement of some 3 to 5 atomic per cent of As by Sb, can be filmed.

Luzonite and stibioluzonite as separate mineral species were not obtained. The conclusion seems to be justified that they may represent the mixed-crystal extremes of antimonial enargite and arsenical famatinite, respectively.

Structure Relationship.

Both enargite and famatinite occur as primary phases and also in mutual intergrowth. All specimens in this system are somewhat inhomogeneous due to the difference in specific gravity of the components. Enargite, for example, is formed often in the arsenic-rich top layer of the button, sinks after solidifying and is indented and dissolved on its edges when it reaches the lower parts of the specimen.

To be concluded in next issue.

THE LEAD–ZINC ORE DEPOSITS AND GEOLOGY OF THE ARBUS AREA IN SARDINIA, ITALY.[1]

CHARLES WILL WRIGHT.

ABSTRACT.

The Arbus area lies in southwest Sardinia, 25 miles north of Iglesias. It is made up of Paleozoic schists intruded by an irregular granite mass about 6 miles in diameter, which together with the surrounding schists, forms a plateau about 1,300 feet above sea level. The floor of the plateau is of weathered granite and surrounding it is a rim of hills made up of the metamorphosed schists.

There are two systems of lead-zinc veins, one in schist parallel to the granite contact, and the other, about normal to the contact, traverses the schists and extends into the granite. The deposits in the schists are lodes up to 60 feet wide, locally rich in both sphalerite and galena and those normal to the granite contact are veins up to 10 feet wide and consisting essentially of galena that is altered to cerrusite for a few hundred feet below the surface. In both systems the minable ore is found in shoots that are about 600 feet long in the lode deposits and about 100 feet long in the vein deposits.

Active mining has been in progress since 1855 when the first mining concessions were granted. The principal concessions are those of Gennamari, Ingurtosu, Montevecchio and Piccalina, the first two belonging to the Societa di Pertusola and the last to the Societa di Montevecchio. The output at present amounts to about 40,000 tons of lead concentrates and 40,000 tons of zinc concentrates a year. These concentrates are reduced to metal at the two companies' lead smelters and electrolytic zinc plants in Italy.

GENERAL GEOLOGY.

FIG. 1 shows the topographic relief and the rock formations that occupy this area. The principal lead and zinc lodes are indicated and a geologic cross-section shows more clearly the structural relationships of these formations.

[1] This article was started in 1912 but never published. At the request of Dr. Alan Bateman the writer is submitting it with apologies in the hope that the material will be of interest and that his presentation will not conflict too severely with today's theories on ore deposition.

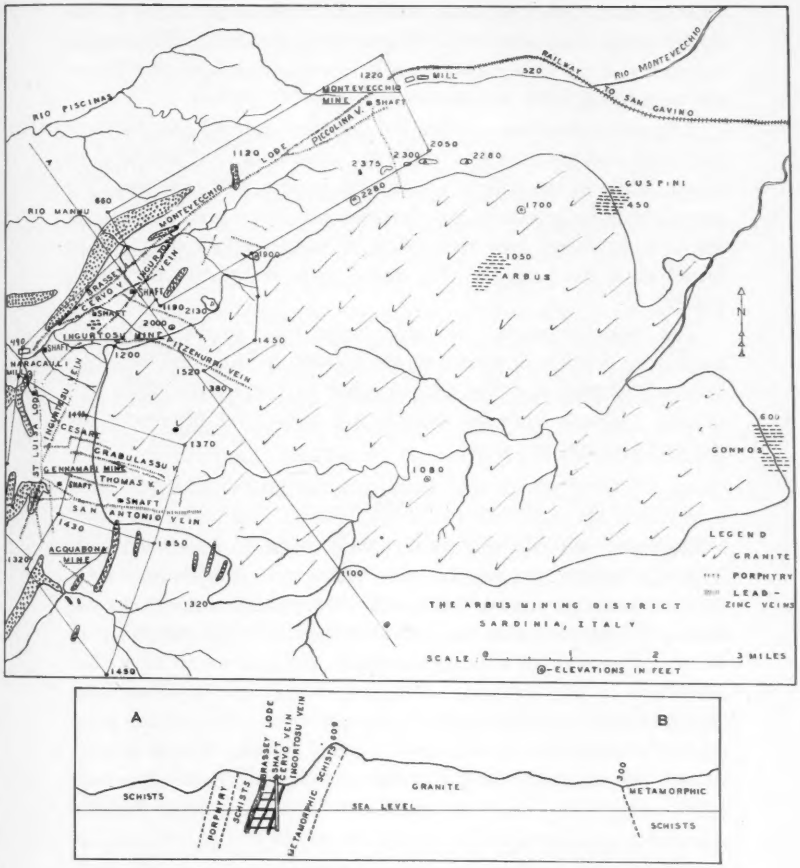


FIG. 1. Geologic map of Arbus mining district, Sardinia, Italy.

Topographically the area consists of a rough uneven plateau from 1,100 to 1,500 feet in elevation, sloping to the east. Partly surrounding it is a chain of hills the principal peaks to the west being Crabulassu at 1,800 feet, Tintillonis at 1,630 feet, Serra Fromigas at 1,800 feet, Conca Flisci at 2,100 feet, and s'Accor-

radrosciu at 2,200 feet to the north, and to the south is the Monte Linas range that rises to a height of 3,900 feet. The varied character of the topography as will be explained is largely due to the underlying rock formations.

The mountain slopes within the area are covered for the most part with scattered trees of wild oak, some cork, and much brush wood, while in the valleys eucalyptus, poplar, and pine trees are abundant, although these, for the most part, have been planted for use as mine timber, new trees being set out to replace them. The brush wood has been used for many years as fuel for the steam plants.

The rock formations in brief consist of a granitic intrusive mass 5 by 8 miles in extent at the surface, surrounded by schist beds of Silurian age that are intruded by porphyritic dikes and masses. Locally both the granite and schists are intersected by the lead and zinc ore veins.

Schists.

Beginning with the sedimentaries are a series of schistose beds in part graphitic and argillaceous, interstratified with beds of a hard siliceous graywacke and locally some schistose conglomerate beds. The stratification in general strikes and dips parallel with the intrusive contact although in places the granite crosscuts the schist beds. The structure of the schist beds is complicated and abrupt changes in strike and dip are common. The schists were evidently subjected to extensive, broad, folding which in part caused the variations in the strike and dip. Wrinkling, minor folds, and gneissic structure are absent. Joint cracks or fracture planes are prominent and in places are so closely spaced as to resemble bedding planes. Faulting of the schist and of the veins with local displacements of many feet has occurred to the west of the granite mass and to a much less extent to the north of the intrusive where the main lodes occur.

The distribution of the schist beds is shown on the accompanying map. Their areal extent is also indicated by the topographic relief as they form the mountain slopes bordering the granite

mass. The age of these schists has been generally assumed to be Silurian although only imperfect fossil remains have been found.

Contact Metamorphism of the Schists.

Contact phenomena between the granite and schist are particularly in evidence at Pitznurri, a hill just above Ingurtosu. Away from the contact the schists are essentially argillaceous and under the microscope seem to be composed of a fine aggregate of quartz grains with laminea of chlorite and white mica; grains of tourmaline and hematite are also present. Certain of the schist beds are graphitic, containing carbonaceous matter, but other strata are decidedly feldspathic and may be classed as graywackes. At about 1,000 feet from the intrusive contact, minute spots may be observed in the schists and brownish particles of biotite gradually become prominent. The schists also become more compact and the chlorite is replaced by the brown mica. Still closer to the contact the schistosity of the beds disappears and they grade into a finely crystalline hornfels. In addition to the quartz and feldspar, biotite is abundant in the hornfels and scattered crystals of cordierite and andalusite occur. Locally, where strata containing essentially quartz or quartz and feldspar are in contact with the granite these have been metamorphosed into a hard, fine-grained, quartzite or feldspathic quartzite with no apparent stratification.

In his excellent work "Le Rocce Granitoidi e Filoniane della Sardegna" Dr. Carlo Riva, with whom I had the pleasure of studying the geology of Sardinia in 1901, describes the contact characteristics at Ingurtosu as follows:

> The zone of hornfels which one observes at the immediate contact with granite is represented in the region between Ingurtosu and Crabulassu by a micaceous-feldspathic hornfels with scattered porphyritic crystalls made up of cordierite and of andalusite: they are therefore cordierite hornfels and cordierite-andalusite hornfels. The accessori minerals include sillimanite, cordundum, zircon, rutile, tourmaline, oxide of iron and carbonaceous substance.

Three samples of the schists representing three stages of metamorphism were taken by Dr. Riva at Ingurtosu near Pitzniuri

and analyses of them, are given under A, B, and C, of Table I.

These samples show only slight changes in chemical composition. C as compared with A shows a decrease in H_2O and the Fe_2O_3 has been almost entirely changed to FeO. These differences were probably caused by the action of the heat given off from the granitic mass.

TABLE I.

ANALYSIS OF SCHISTS AND GRANITE.

	A	*B*	*C*	*D*
SiO_2	56.65	55.53	55.71	72.30
TiO_2	0.79	0.80	1.08	0.20
Al_2O_3	17.98	20.70	20.54	13.96
Fe_2O_3	5.54	3.22	0.83	0.30
FeO	4.54	6.03	6.93	1.70
MgO	3.76	3.96	2.77	0.60
CaO	0.40	0.30	0.62	2.13
Na_2O	0.76	0.53	1.29	3.00
K_2O	5.14	6.21	7.12	4.50
H_2O	4.47	3.54	2.28	0.40
	100.03	100.62	99.17	99.29

A. Argillaceous schist with small spots (slightly metamorphosed).
B. Micaceous schist with spots (metamorphosed).
C. Hornfels (much metamorphosed).
D. Granite of Ingurtosu.

The contact zone is defined by mountain ridges made up of these metamorphosed schists, which resisted the action of weathering. The granitic core on the other hand was more easily eroded and forms an irregular surface several miles wide sloping gradually toward the east and forming the valley between the villages of Arbus and Gonnos.

Granitic Intrusive Mass.

The granite is part of a batholith exposed over an area 8 miles long and 5 miles wide. Its composition and texture are quite uniform except for surface decomposition and alteration adjacent to the veins, and at its immediate contact. The unaltered granite is light gray in color, quartz, feldspar and biotite being the dominant components. The feldspar is essentially orthoclase and

microcline with some ablite occurring in thin plates throughout the rock. Abundant biotite constitutes the essential colored component. Muscovite is also present in the altered granite but is probably a secondary mineral formed by the decomposition of the feldspars. Pyroxene and amphibole are rare. Of the accessory minerals magnetite, pyrite, apatite, zircon and titanite are present in minute crystals. The decomposed granite is of a yellowish brown color, caused by the oxidation of its pyrite and magnetite content and the feldspars are altered to kaolin, muscovite and quartz.

Dr. Riva classes the granitoid rocks of Sardinia as granites and only a small portion of them are referred to as diorites. Other writers have classed them as granitite for the reason that biotite is in most cases the only mica present. An analysis of unaltered granite from Ingurtosu taken by Dr. Riva is given in Table I, *D*.

Near its contact with the schists certain differentiation phenomena of the granitic batholith may be observed. Segregations of the more basic minerals principally biotite occur and the granite is of a dark grey color with a fine grained texture. Adjacent to such basic segregations the granite is commonly more siliceous and has a coarse pegmatitic texture. Inclusions of angular blocks resembling fragments of the highly metamorphosed schist are common, some of which appear to grade into the granite without any line of demarkation, suggesting that these inclusions were in part absorbed by the enclosing granitic magma. Both the granite and schists near the contact contain many pegmatite and aplite dikes, as well as quartz veins varying from less than an inch to a few feet in width; also, small dikes of granite penetrate the schists locally. In certain of the quartz-feldspar veins, pyrite, some chalcopyrite associated with epidote crystals, and flakes of molybdenite were found.

Porphyritic Intrusives.

Numerous porphyry dikes and masses invade the schists a short distance from the granite. They are unevenly distributed

and form irregular masses, some apparently in the form of laccoliths and dikes of variable width and indefinite continuity. Microscopic examinations by Dr. Riva show them to be quartz granophyr with a porphyritic texture.

The porphyry dikes are locally intersected by the ore veins as at the Gennamari Mine where both the S. Anna and Idina veins traverse porphyry. The porphyry intrusives are all older than the mineral veins and it is doubtful whether they have had anything to do with their formation.

Other intrusive rocks, basic in composition, rarely occur in the form of dikes from one to two meters in width. Some of these resemble augite porphyrite and others diabase. These dikes intersect the mineral veins and are, therefore, of later formation.

To the north of the Montevecchio mine is an extensive area covered with Tertiary lavas, and the rock formations on the western portion of the area toward the sea are buried under sand dunes that extend for some miles inland.

ORE DEPOSITS.

As already mentioned, there are two main systems of fissuring within the Arbus area each with distinctive vein filling.

One system consists of a series of veins forming a main lode and individual veins confined to the schists. In general they are parallel to the granite contact and from one-half to two kilometers from it. These veins contain galena and blende in variable proportions, also small amounts of pyrite and chalcopyrite, and as gangue minerals barite, siderite and some quartz and calcite. The lodes and veins of this system are the most important and include the Montevecchio-Brassey lode and the Ingurtosu, Cervo and Idina veins.

The second system of veins occupy fissures approximately normal to the granite contact and to the first system of fissures. They traverse the schists and certain of them extend for some kilometers into the granite. They are intersected and displaced a few meters or more by the veins of the first system. Galena and cerrusite also pyromorphite constitute the minerals of value,

the gangue minerals being quartz and siderite in about equal proportions.

Lodes and Veins Parallel to the Granite Contact.

The lodes and veins of the first system, as shown on the map, extend from the eastern part of the Montevecchio concessions southwesterly for nearly 5 miles to Naracauli, at the west end of the Ingurtosu Concession. The principal lodes and veins along this portion of the mineral zone are the Montevecchio, Brassey, Piccalina, Ingurtosu and Cervo. The continuity of these veins is interrupted at Naracauli where the zone of fissuring as well as stratification of the schists bends to the south. Along the western side of the granite, the mineral zone assumes a southerly direction through the center of the Gennamari Concession. Rich ore shoots along this zone occur in the Pinnadeddu valley where the supposed continuation of the Brassey lode and Ingurtosu vein is being mined, and at the south end of the Gennamari concession where the Idina Vein occurs, which is believed to be an extension of the Ingurtosu Vein. South of the Gennamari Concession there is another interruption, the strike of the veins changing to the southeast. The zinc-lead lodes of the S'Aqua Bona Mine represent the southeast extension of this vein system parallel to the granite contact.

Faults locally cut the veins and displace them a few feet, although in certain instances the veins have not been found beyond the faults. These lodes displace the veins that lie normal to contact.

The Main Lode.—The Main Lode, which constitutes the principal deposit at the Montevecchio Mine and the Brassey section of the Ingurtosu Mine, is one of the most important lead-zinc deposits in Europe and yields about one-half of the lead production of Italy. Its outcrop projects high above the enclosing schists and is traceable in a straight line over the hills in an east west direction for about 4 miles, then curving to the southeast on the Ingurtosu concession for an additional 2 miles. Isolated outcrops may also be observed at other points around the granite

contact. On the Montevecchio concession three veins occur across a width of 300 feet and to the west these separate to over a thousand feet apart. Only the western portion of this lode, namely, the Brassey section, is described, as the writer is more familiar with it. This section has been developed over a length of 2 miles along which length 3 ore-shoots occur. These are from 1,200 to 2,000 feet long and are separated by 1,500 to 2,000 feet of almost barren portions of the lode. These shoots or minable portions of the lode vary from 15 to 50 feet in width and have been developed by adits and shafts to about 600 feet in depth.

The ore consists essentially of zinc-blende and galena mixed with pyrite, some chalcopyrite, barite, siderite, calcite and quartz. In places, the ore body is a wide brecciated mass with the ore minerals forming the matrix between fragments of schist that range up to several feet in diameter. At other points where the schist is less disturbed, there are veins of ore and gangue minerals quite irregular and intersecting one another, some of siderite or zincblende and some of quartz with galena. Both the zincblende and galena are coarsely crystalline and occur in solid patches up to several feet across, as well as scattered through the veins and disseminated in the enclosed fragments of schist.

There are many miles of workings along this lode. From certain stopes a large proportion of hand-sorted galena and blende is obtained and from other stopes all of the ore mined is sent directly to the concentrating plant. The ore shoots contain about 8 per cent zinc and 3 per cent lead. From one-fifth to one-tenth of a ton of concentrates are produced per ton of ore mined, the average being about 1 to 8.

Mining is done by the cut-and-fill method, the filling being introduced through raises that extend to the surface. Considerable timber is required in certain stopes but in others the roof stands without timber. The lode is practically barren for the first 20 to 40 feet below the surface, this representing the extent of the zone of oxidation. Surface pits have been made in these oxidized portions to obtain the necessary rock filling for the stopes below.

It is noteworthy that on the lowest levels the lode is just as rich if not richer than on the upper levels and there is every reason to believe that these ore shoots may persist in depth as far as it will be possible to extend mining operations.

The production from the Brassey section of this lode since 1900 has amounted to about 350,000 tons of blende concentrates and 80,000 tons of galena concentrates. Zincblende is more dominant in this western half of the lode than in the Montevecchio or eastern half, where galena is more abundant.

Ingurtosu Vein.—The Ingurtosu Vein occupies a fairly well defined fissure parallel to and about 1,800 feet southeast of the Brassey Lode. It is from 3 to 6 feet wide and has been developed for 5,000 feet in length, it dips 75° NW. From the main vein, branch veins extend into the hanging wall for distances up to a few hundred feet, and from 10 to 60 feet away from the main vein. The ore in the main vein occurs in irregular shoots that have a flat pitch. Because of the irregularity of the ore occurrence, the stopes are generally pushed upward through waste portions of the veins in order to mine the richer patches of ore just above. These so-called "galena patches" are mostly relatively small, under a hundred square feet in area, and unless diligently searched for they may readily be missed.

The galena is quite massive in this lode and occurs with quartz and some blende. Mineralized fragments of the schist also form a part of the gangue and locally pyrite and some chalcopyrite may be present. The average tenor of the ore mined has been about 8 per cent lead and 2 to 3 per cent zinc. From this vein, 40 per cent of the galena is obtained by hand-sorting and hand-jigging, while 60 per cent of the galena and all of the blende is obtained in the mill.

In most of the stopes a sufficient amount of waste rock is obtained from the veins and walls for the necessary filling. Locally, where the schist walls are weak, timbering is required in the stopes.

The tenor of the lead product from the vein averages 68 per cent lead with 420 grams of silver per ton, and that of the blende is about 53 per cent zinc. This vein yields about 2,000 tons of

lead concentrates and 300 tons of zinc concentrates annually.

Cervo Vein.—This is another interesting vein and may be considered an intermediate type both as to its position and mineral content. It lies between the Brassey lode, which is rich in zinc-blende, and the Ingurtosu vein, which is rich in galena. The Cervo vein also lies at more of an angle to the granite contact than the other two. In size it corresponds to the Ingurtosu vein although it is less extensive. Except for the higher zinc and lower lead content, the mineralization resembles that of the Ingurtosu vein.

Veins Normal to the Granite Contact.

The veins of this system occur as radial veins nearly at right angles to the contact of the granite and extend for a mile or more into the granite as well as into the schists. They are intersected as well as faulted by the other vein system and hence are older. They have well defined walls, vary from 3 to 10 feet in width, and dip steeply. In these veins the galena occurs in small masses scattered throughout the siderite-quartz gangue. Pyrite is present in small amounts and the absence of blende in this vein system is characteristic.

The principal veins belonging to this system are the San Antonio, Crabulassu, Thomas and Tintillonis. A detailed description of the San Antonio vein alone will suffice to show their general characteristics.

San Antonio.—The initial workings on this vein date back seventy years and they now extend over a length of 2 miles along the strike and include 10 miles of levels. About one-third of the vein thus far mined is in the schist and two-thirds of the workings are in granite. The strike of the vein is N 60° W and the dip is 75° NE. The stopes that yield the richest ore are generally those near the contact and at the extremities of the vein, both in the granite and in the schist, there is a decrease in the lead content. The ore in this vein occurs irregularly distributed and, although local and fairly extensive concentrations are present, no continuous ore shoots have been defined. The ore is essentially

galena although much carbonate of lead has been mined from the stopes nearest the surface. The gangue consists of siderite and quartz in about equal proportions, and either altered granite or mineralized inclusions of schist. Locally minor pyrite is present. The walls of the granite are generally decomposed and the vein itself contains many cavities and cracks. Thus in mining, the dynamite consumption is not high and the stopes, being narrow, require but little timber. The average lead content of the ore mined from the San Antonio Vein is about 5 per cent. About 35 per cent of the production is obtained by hand sorting and hand jigging and the rest is extracted in the mill.

The total production of concentrates from the San Antonio Vein from 1900 has been about 60,000 tons. The tenor of the product averages 56 per cent lead and 400 grams silver per ton.

Of the other veins, Crabulassu is next in importance and differs in so far as it contains a greater amount of secondary lead minerals, principally cerrussite and pyromorphite, and less galena. It is also poor in silver. The Thomas and Tintillonis Veins are small and less oxidized, containing more quartz and practically no secondary lead minerals.

GENESIS.

The geologic events responsible for the ore deposits and that can be deciphered from the present rock formations and phenomena produced, began with the intrusion of the granite. If it can be correlated with similar granitic masses on the island, the period of its intrusion can be determined only as pre-Triassic and post-Devonian. The intrusion may have occurred during the Carboniferous or Jurassic period. The invasion of magma in the Arbus area uplifted the schists, metamorphosed the parts adjacent to the contact, and forced them to conform structurally in a general way with its contact surface. These forces also caused a fracturing of the adjacent schists and of the solidified portion of the granite near the contact. Such fractures were subsequently filled with aplite, pegmatite and quartz. The intrusion of porphyritic dikes and masses in the surrounding schists, in

some instances up to several miles from the granite contact, are considered to be a still later phase of the igneous activity, and judging from the analysis these porphyries were probably derived from the same underlying magma that formed the granite.

Subsequent to this granitic intrusion and metamorphism of the intruded rocks, fissures were formed both in the schist and granite as well as in the porphyry. The oldest system of fissures, which are nearly normal to the granite contact, are in turn intersected by the later fissure system, which is approximately parallel with the contact. A study of these fissure veins and lodes shows that the minerals were introduced into them at different epochs evidently after disturbances that reopened the fissures and allowed re-entry of the mineralizing solutions.

It has been suggested that the formation of these fissures was caused by the cooling and accompanying shrinkage of the granite mass and their positions normal and parallel to the contact seem to emphasize this hypothesis. However, they must have been formed long after the granite had solidified to a great depth, and after the intrusion and solidification of the prophyry masses that are later than the granite. As these fissure veins are not contemporaneous with each other nor with the intrusives in which they occur, it is probable that other causes may account better for their formation.

The same magma chamber that yielded the Arbus granite has doubtless also yielded the porphyry dikes and masses. The same underlying forces that caused such masses of magma to break through the overlying sedimentary rocks, may have been active at a later period and caused the fissuring. One may possibly attribute at least the veins that parallel the contact to a subsidence of the solidified granite mass possibly due to a transfer of molten magma from its chamber causing it to sink slightly. This sinking would be followed by an isostatic readjustment causing the surrounding schists to crack or fissure; similar readjustments may have occurred at different periods causing reopening of the veins. The later displacements or faults in the schist beds may be attributed to similar causes.

The source of the mineralizing solutions that yielded the ores can only be conjectured. The simplest and most probable source seems to be that from which the granite porphyry and pegmatite dikes were derived, namely the underlying magma, which during the intrusion of the granite within this area was brought relatively near to the surface. Magmas are known to contain metallic minerals in minute quantities as well as large quantities of water in a superheated state. These metal-bearing minerals being more volatile than the non-metallic minerals may possibly emanate and circulate at a great depth along with the water from the magma in the form of vapor during their process of cooling. This vapor together with the saturated mineral salts is supposed to force its way upward into the cooler zones, where it condenses into liquid or mineral bearing water, flows along the fissures and penetrates the adjacent rocks where its mineral content is precipitated as the temperature of the solution becomes lower. The fissures may fill and again be reopened by the same disturbances that caused the original fissuring and a new supply of mineral-bearing solutions may pass along them precipitating different minerals and this may explain the presence of certain veins richer in some minerals than adjacent veins of the same system. It is also noteworthy that the older system of veins contain little or no zinc ore whereas the younger or main lode parallel to and away from the granite contact is richer in zinc ore than the veins of the same system closer to the contact such as the Ingurtosu vein.

LONDON, ENGLAND,
Aug. 23, 1938.

GEOLOGY OF THE BONANZA KING MINE, HUMBOLDT RANGE, PERSHING COUNTY, NEVADA.[1]

DONALD F. CAMPBELL.

ABSTRACT.

The Bonanza King mine lies on the east slope of the Humboldt Range, and in an area of folded and faulted Triassic volcanics.

The ore body is a sulphide quartz vein carrying gold and silver, associated with fractures in a diabasic dike.

Primary minerals are quartz, pyrite, tetrahedrite (argentiferous), galena, sphalerite, chalcopyrite and native gold. Secondary enrichment appears to have yielded covellite, chalcocite, stephanite, and argentite. After deposition of most of the quartz and sulphides, reopening of the fracture permitted the deposition of additional quartz, together with tourmaline and some more sulphides. The solutions are thought to have come from a neighboring granodiorite stock, and the deposits are regarded as mesothermal or possibly hypothermal.

INTRODUCTION.

THE Bonanza King Mine is located in Pershing County, Nevada, on the lower part of the east slope of the Humboldt Range, 27 miles northeast of Lovelock, Nevada.

The lode was discovered in 1868 and some ore was shipped from the property. A mill was erected in 1873, and the mine was operated irregularly until 1910. Between 1910 and 1934 the mine lay idle although the deposit had not been worked out.

GEOLOGY OF THE HUMBOLDT RANGE.

The geology of the Humboldt Range has been described by Hague,[2] King,[3] Ransome,[4] Knopf,[5] Louderback,[6] Jenney[7] and

[1] The writer wishes to acknowledge the kindness of Mr. Frank R. McDonald whose courtesy made possible a study of this ore deposit. Grateful acknowledgment is also due Professors H. Ries and C. M. Nevin of Cornell University for their suggestions and criticisms.

[2] Hague, Arnold: Descriptive geology. U. S. Geol. Expl. 40th Par. Rept. 2: 713–731, 1877.

others. The most detailed work has been done by Knopf and Jenney, that of the latter being the most recent.

The oldest rocks exposed are Triassic volcanics named the Koipato series by King. The basal member of the series is a keratophyre made up of flows and pyroclastics, which, according to Jenney, have a thickness of 6,000 feet. These include: (1) A basal member of keratophyre flows and pyroclastics, 5,000 feet thick (Jenney); (2) the Rochester rhyolite, about 5,000 feet of rhyolite flows and pyroclastics (Jenney)[8]; (3) rhyolite tuffs and breccias of variable thickness, ranging from 400–800 feet on the west side of the range, but much thinner in the Bonanza King mine; and (4) the Weaver rhyolite up to 700 feet thick (Knopf).

The volcanic rocks are overlain by Middle Triassic limestone of the *Daonella dubia* zone, and the fact that it overlies the volcanics conformably has been the basis for assigning a Triassic age to them. The limestones are thought to be about 2,000 feet thick.

All of the above mentioned rocks were folded into a broad arch and cut by granitic intrusives composed of aplites, granites, granite porphyries, and granodiorites. Folding and intrusion are thought to have taken place at the close of the Jurassic during the post-Jurassic revolution that affected the entire Sierra Nevada region. Basalt flows of probable Pliocene age can be seen at many places along the foothills of the range. The canyon floors are covered by coarse angular gravel in places over 100 feet thick, which grades into the alluvial fans along the foot of the range.

The structure of the range is the result of two periods of orogeny. The earlier one probably coincided with the Post-

[3] King, Clarence: Systematic geology. U. S. Geol. Expl. 40th Par. Rept. 4: Pt. I, 1878.

[4] Ransome, F. L.: Notes on some mining districts in Humboldt County, Nev. U. S. Geol. Surv. Bull. 414, 1909.

[5] Knopf, A.: Geology and ore deposits of the Rochester District, Nevada. U. S. Geol. Surv. Bull. 762, 1924.

[6] Louderback, G. D.: Basin range structure of the Humboldt region. Geol. Soc. Amer. Bull. 15: 289–346, 1904.

[7] Jenney, C. P.: Geology of the Central Humboldt Range, Nev., Univ. of Nev. Bull. XXIX, 1935.

[8] Jenney, C. P.: Idem, p. 23.

Jurassic revolution at which time the Triassic rocks were folded into a broad anticline and were intruded by the igneous core of the range. The second took place late in the Tertiary when extensive block faulting uplifted the Humboldt Range and initiated the present topography.

GEOLOGY OF THE MINE AREA.

The Bonanza King mine lies on the east limb of the broad arch of Triassic rocks, and is near the contact of the limestone with the underlying rhyolites. The formations in the mine area strike north-south and dip about 30° so that the outcrops form N–S trending bands.

The detailed faulting in the vicinity of the mine is shown in Fig. 1. The geologic section in the mine area is as follows:

Recent	Wash
Tertiary	Basalt
Jura-Cretaceous	Altered diabasic dike
Triassic	Limestone
	Tuffaceous phase at base of limestone
	Porphyritic rhyolite (Weaver rhyolite)
	Purple rhyolitic tuffs
	Rhyolites-lavas, tuffs (Rochester rhyolite)

Triassic Volcanic Rocks.

Rhyolites.—These are the oldest rocks in the mine area, both lavas and tuffs being present. They can be correlated with the Rochester rhyolite described by Jenney [9] and the Rochester trachyte mentioned by Knopf.[10] They are variable in color and texture with numerous phenocrysts of quartz and a lesser amount of orthoclase and albite.

Hydrothermal alteration of these rhyolitic rocks is widespread and consists chiefly of the development of sericite and fine grained quartz.

Purple Tuff.—At the top of the rhyolite series just described is a tuff of purplish red color containing fragments of felsitic

[9] Jenney, C. P.: Idem, p. 23.
[10] Knopf, A.: *loc. cit.*, p. 14.

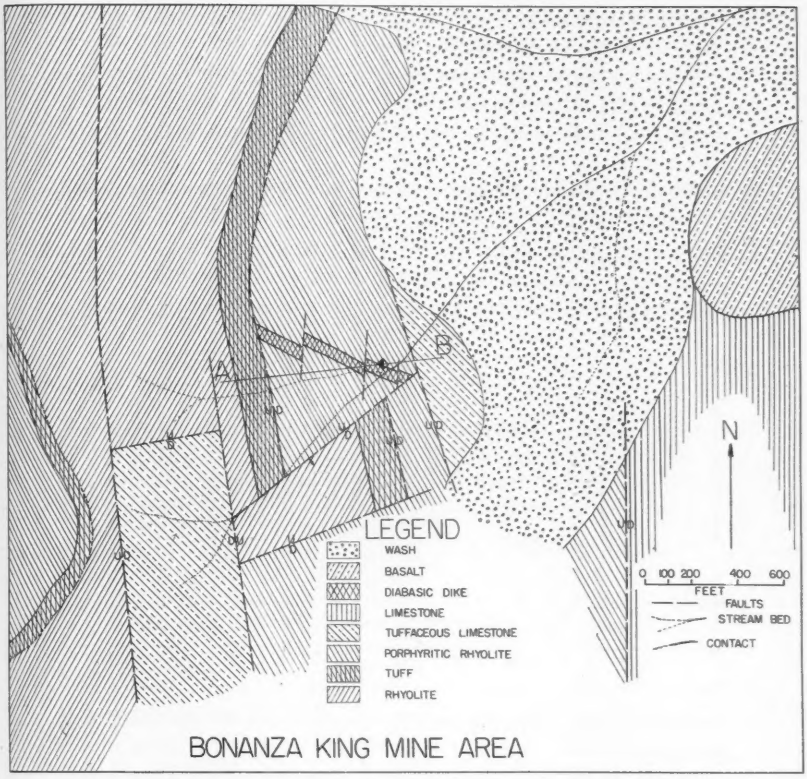


FIG. 1.

lavas. The tuff serves as an important key zone to use in mapping the faults in the mine area. The thickness of the bed as exposed in a gully west of the shaft is 65–70 feet, but it is separated from the overlying porphyritic rhyolite by a strike fault.

Porphyritic Rhyolite.—The dike in which the Bonanza King vein occurs cuts a body of pophyritic rhyolite whose porphyritic texture indicates that it may have been intruded beneath the Triassic limestones. In this connection it should be noted that

this variety of rock is scarce on the east side of the range at the latitude of the Bonanza King Mine.

Both the top and bottom contacts of the porphyritic rhyolite are strike fault contacts so that the thickness of the formation is not known, but about 285 feet of rhyolite are exposed at the mine (Fig. 2).

The rock is light-colored and contains conspicuous phenocrysts of quartz and orthoclase. The groundmass is dense, stony, and has a slight greenish hue. The rock contains no dark minerals. Under the microscope the groundmass is seen to be composed of quartz and feldspar, but hydrothermal alteration, widespread in

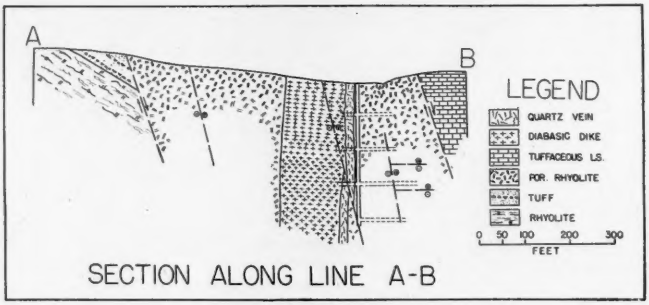


FIG. 2.

the region, has developed sericite around some of the unaltered phenocrysts.

This rock fits the description of Knopf [11] and Jenney [12] for portions of Weaver rhyolite. In the mine area, however, neither the Weaver rhyolite nor the underlying tuffs are as thick as they are on the west side and along the summit of the range.

Triassic Sedimentary Rocks.

Limestone.—The basal portion of the limestone along the east side of the range contains shaly beds, which under the microscope

11 Knopf, A.: *loc. cit.*, p. 27.
12 Jenney, C. P.: *loc. cit.*, p. 28.

are seen to contain tuffaceous material. This indicates that during the early part of limestone deposition volcanic materials were being supplied to the sea. These tuffaceous beds form a key zone that is useful in mapping the faults in the mine area. Their absence at many points along the foot of the range indicates a major strike fault.

The limestone proper outcrops in a wide belt along the east foot of the range. It has been shown on paleontological evidence by Smith to be of Middle and Upper Triassic age and is known as the Star Peak formation.[13]

Post-Jurassic Intrusives.

Granodiorite.—In lower Spring Valley, a little over one-half mile northwest of the mine, is a small stock-like mass of light colored intrusive rock with a granitoid texture. Megascopically, some parts of it consist of feldspar, quartz, and a little biotite. In other parts of the mass the rock contains hornblende phenocrysts up to ¼ of an inch in length. In places hornblende is absent and biotite aggregates resulting from its alteration are found.

Microscopic examination shows that all of these phases of the intrusive have the mineral composition of a granodiorite or quartz monzonite. Feldspar makes up 70 to 80 per cent of the rock, quartz 5 to 10 per cent. Orthoclase constitutes roughly ⅓ and andesine ⅔ of the feldspar. The chief mafic mineral is hornblende, which has been largely altered to biotite. The writer prefers to call the intrusive a granodiorite because plagioclase is present in considerable excess over orthoclase.

Diabasic Dike.[14]—Cutting the porphyritic Weaver rhyolite, and visible at the Bonanza King mine, is an altered dike about 45 feet thick that dips vertically and strikes N. 60° W. The Bonanza King vein (Fig. 3) occurs in this dike, which is more altered and finer grained than the granodiorite. Its color is

[13] Smith, J. P.: The Middle Triassic marine invertebrate fauna of North America. U. S. Geol. Surv. Prof. Pap. 83: 8–9, 1914.

[14] Since the texture of the dike rock in less altered hand specimens and in thin sections is ophitic, the term, "diabasic" has been applied to it.

greenish gray where not stained with limonite. Carbonate and chlorite are recognizable in hand specimens, and the rock shows a silky luster characteristic of sericitized material.

Because of the intense alteration most thin sections of the dike rock give no evidence of its original composition. However, one specimen of it, protected by gouge, was found to contain about 85 per cent feldspar (70 per cent andesine and 15 per cent orthoclase). Other thin sections of the dike rock show chlorite as an alteration product of the original ferromagnesian minerals.

From this evidence it was concluded that the dike is closely related in composition to the stock, in fact it is thought to be an offshoot from the granodiorite mass. The surface trend of the dike toward the stock helps support this conclusion.

Hydrothermal alteration of the dike consists chiefly of sericitization and carbonatization, but there has been a lesser development of epidote, chlorite and pyrite. The sericite has formed chiefly from the feldspars, and in general is more abundant near the vein. Associated with the sericite is fine grained quartz. The carbonate is later than the sericite. In places, particularly within ten feet of the vein, carbonate is so abundant that the rock will effervesce with cold dilute hydrochloric acid. Epidote, derived by alteration of the feldspars, is fairly common. There is also considerable pyrite disseminated throughout the rock.

In less altered portions of the dike, chlorite formed in part, at least, by alteration of hornblende is common. Since chlorite is present in the Spring Valley stock, it is concluded that the chlorite in the dike need not necessarily have been formed by hydrothermal solutions associated with the vein deposition.

Where pyrite in the dike has been oxidized to limonite the dike assumes a yellowish brown color.

Age of Intrusives.—The age of intrusive rocks is post-Triassic, probably late Jurassic. Jenney [15] gives a summary of the evidence of the age of the intrusives. Near Winnemucca, 40 miles northeast of the area, granodiorite intrusions cut Jurassic strata.

[15] Jenney, C. P.: *loc. cit.*, p. 46.

It is thought that the intrusion took place during the Jura- Cretaceous orogeny that affected the entire Sierra Nevada region.

Tertiary Volcanic Rocks.

Basalt commonly caps the hills along the east front of the range. It is generally black in color and fine-grained with small feldspar crystals; in places it is scoriaceous.

Knopf [16] considers the basalt to be of late Pliocene age because it rests in places on coarse alluvial material that is probably

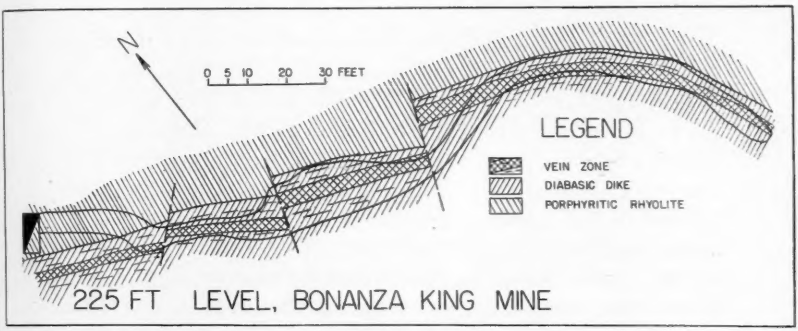


FIG. 3.

of Pliocene age. This relationship was noted about ½ mile east of the Bonanza King Mine.

Tuff.—In some parts of the area a porous brick-red tuff occurs between the basalt and the Triassic limestone.

Recent Alluvial Material.

Alluvial material is widespread in the mine area. Spring Valley Canyon to the north, and Dry Gulch to the south of the mine, both have deep gravel fills from which considerable placer gold has been recovered. The most probable explanation of the deep gravel fill in the canyons is the gradual filling of the intermontane basin, and such filling probably occurred while the basins

16 Knopf, A.: *loc. cit.*, p. 37.

were occupied by Lake Lahontan.[17] The fill in the canyons is commonly deeply gullied by the present streams, this erosion probably having occurred after the disappearance of Lake Lahonton, in which the Humboldt Range stood as an island. The base level of the streams was thus lowered, permitting down-cutting. It should be noted that the fill in the canyons indicates that the ground water level has risen recently, and this has an important bearing on the oxidation of the ore deposit, as will be explained later.

STRUCTURE OF THE MINE AREA.

In addition to the folding that has affected the area, the rocks are cut by numerous faults, mostly of normal type with an easterly dip (Fig. 3). The major faults have a N.–S. trend and the blocks between them are cut by cross faults. The folding is considered to have taken place at the end of the Jurassic, at which time the granodiorite was intruded. The normal faulting is attributed to late Tertiary orogeny when the present topography was initiated by block faulting.

The Bonanza King dike and the ore-bearing vein contained in it have been displaced by several cross faults (Figs. 1, 2, 3), the east side having been moved north relative to the west side. The orebody is also displaced by a few horizontal faults, and the hanging wall of these has moved north relative to the footwall. The writer believes that the cross faults and horizontal faults that displace the vein were formed as a result of the overthrusting along the NE.–SW. trending fault that lies south of the mine. It is reasonable to suppose that the Bonanza King dike was intruded along a fault fissure, which probably belongs to the earliest group of faults in the mine area.

The vein occupies a fissure partly along the north wall of the dike and partly within it, and it seems probable that this fissure was opened by a continuation of the same stresses that formed the fracture along which the dike was intruded.

[17] Russell, I. C.: Geologic history of Lake Lahontan. U. S. Geol. Surv. Mon. 11 1885.

Both the dike rock and the vein quartz show considerable crushing, some of which occurred before the mineral-bearing solutions were entirely exhausted, because thin sections of the vein material show two ages of quartz. Early coarse-grained quartz is cut by stringers of fine-grained quartz and polished sections of the ore show that the sulphides have been shattered and re-cemented by narrow quartz stringers. The extensive later crushing affecting both vein and the adjacent dike rock was largely due to later renewed movement along the fracture containing the vein, since the crushing was no greater near the cross faults than away from them.

Much of the faulting in the area is post-mineral, and it is possible that there has been more than one period of post-mineral faulting in addition to that which crushed the vein material; however, underground data are too incomplete to classify the faults into groups.

ORE DEPOSIT.

General Features.—The Bonanza King ore body is a quartz vein containing various sulphides, some of which carry gold and silver. The deposit may be classed as high grade.

The vein lies in the altered diabasic dike at a varying distance from the north wall but rarely more than four or five feet from it (Fig. 3). Both dike and vein are nearly vertical and strike about N. 60° W. The main vein is from 2½ to 5 feet wide with a zone of closely spaced quartz stringers in the altered dike rock on either side. The average width of the vein zone is about 8 feet, but the metallization has been mostly in the main vein.

Ore.—The ore is siliceous and the sulphides constitute less than 10 per cent of its volume. About 80 per cent of the value of the ore is in gold and 20 per cent is in silver.

The primary minerals are coarsely crystalline quartz, pyrite, tetrahedrite, galena, sphalerite, chalcopyrite, and native gold, their relative abundance being in the order named. Visible gold occurs as flakes in limonite areas formed by oxidation of pyrite, in tetrahedrite or in the copper carbonates formed from it, and

rarely in the galena. Pyrite is the most important carrier of gold with tetrahedrite second in importance. No visible gold was observed in the quartz.

It is thought that most of the primary silver in the ore is present in the tetrahedrite since it gives a strong test for silver. Tetrahedrite is also the primary source of the silver in Rochester mines.[18]

Polished surfaces show a silver sulphantimonide, apparently stephanite, and argentite replacing the galena along the cleavages (Fig. 4), but these minerals are considered to be secondary. Polished specimens of the ore give no conclusive evidence as to the order of deposition of the sulphides but they do show that the sulphides replace the vein quartz. In places pyrite is seen megascopically to replace quartz. Since the sulphides constitute such a small part of the vein material, they are rarely seen to be in contact with each other, and even where they are it is generally impossible to say definitely whether one has replaced the other.

The chalcopyrite in the ore is closely associated with sphalerite; nearly every grain of the latter shows inclusions of the former (Fig. 5). Teas suggested that this relationship was caused by chalcopyrite replacing the sphalerite,[19] but Buerger,[20] by means of laboratory experiments, has proved the existence of a solid solution of chalcopyrite in sphalerite and the unmixing of chalcopyrite from such a solution.

The sulphides are shattered and intersected by quartz (Figs. 5 and 6). As has been mentioned earlier, the quartz of the veinlets in the sulphides is fine-grained and is later in age than the main mass of vein material. In crushed portions of the vein the fragments are surrounded by limonitic stain from oxidizing solutions, and the limonite has partially re-cemented the crushed material. There are other crushed areas, especially in the main vein where crushed fragments have been re-cemented with quartz. In some crushed and re-cemented places there are cavities lined with small quartz crystals, or with azurite crystals.

[18] Knopf, A.: *loc. cit.*, p. 48.

[19] Teas, L. P.: A. I. M. E. Trans., 59: 68–72, 1918.

[20] Buerger, N. W.: Amer. Min., 19: No. 11, 1934.

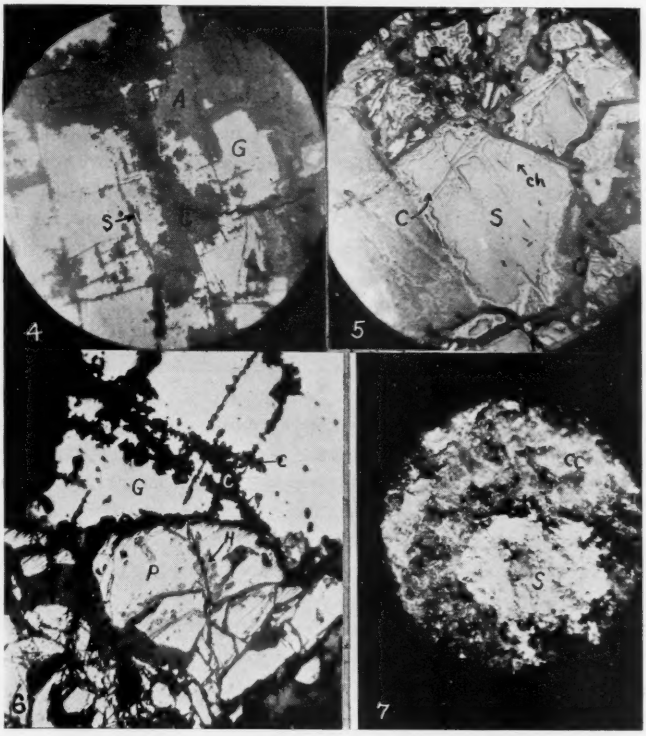


FIG. 4. Galena replaced by argentite (A) and stephanite (S) and altering to cerussite (C). × 30.

FIG. 5. Sphalerite (S) replaced by covellite (C). Note chalcopyrite (ch) flecks in sphalerite and veinlets of later quartz (Q) cutting the sulphides. × 30.

FIG. 6. Pyrite (P) replaced by hematite (H), fractured and re-cemented by quartz (Q). Galena (G) altering to cerussite (C). × 37.

FIG. 7. Native silver (S) on copper carbonate (CC). × 12.

An unusual feature of this deposit is the presence of tourmaline which is as abundant as the combined sulphides, and commonly gives rise to a banded structure in the vein. It is fine-grained, particularly in the center of the main vein, and the bands

are only about 1/16 of an inch thick. Closely spaced groups of thin bands give the impression of a wide one. The tourmaline has replaced the quartz.

Sulphides rarely occur in the tourmaline bands, but are disseminated in the quartz beside them. In places the sulphides are continuous enough to form indistinct bands that are roughly parallel to those of tourmaline but which are not in contact with them.

The banding of the vein is cut by numerous cross fractures, some of which show displacements up to ⅜ of an inch, but these post-date the primary mineral deposition. They have, however, served as channels for oxidizing solutions. They are in places occupied by thin films of sericite, but this mineral also fills fractures that are parallel to the banding of the vein. In places veinlets of carbonate ¼ of an inch or less in width parallel the tourmaline bands, but may cross them. Carbonate deposition began after that of the tourmaline but before sericite deposition had ceased. The sericite and carbonate were apparently formed during the later stages of hydrothermal activity after the sulphide mineralization and the formation of tourmaline.

Tourmaline was certainly not introduced at the same time as the sulphides. Thin sections show that it is associated with the fine-grained quartz, and this, together with the fact that the tourmaline commonly occurs in the center of the main vein, leads to the conclusion that it is later than the bulk of the sulphides.

OXIDATION.

Oxidizing solutions have penetrated the deposit along fractures in the quartz to the greatest depth of mining, which is 300 feet. The present ground water level is only 75 feet below the collar of the shaft, therefore it must in the past have been considerably deeper. The rise of the water table is attributed to the gradual filling of the intermontane basin by debris washed in from the surrounding ranges.

The following oxidized minerals have been identified in the deposit: goethite, hematite, azurite, malachite, chrysocolla, cerussite, and smithsonite.

Pyrite is the source of the goethite and hematite. Limonite stains penetrate the ore along post sulphide fractures, and the dike rock is also highly stained. In polished sections, hematite is seen to replace pyrite although it is not readily visible in hand specimens. No limonite was observed to have formed directly from pyrite, which indicates that in the Bonanza King deposit the formation of limonite from pyrite went through an intermediate hematite stage.

The entire ore body, so far as developed, shows blue and green stains and crusts of azurite, malachite, and chrysocolla. In some hand specimens these minerals have the appearance of having formed directly from the tetrahedrite.

Polished sections show chalcocite, covellite, and a chalcocite-covellite mixture altering to copper carbonates. No instances were noted of copper carbonates having formed directly from the tetrahedrite. The tetrahedrite that was accessible to descending solutions was enriched by a coating of secondary copper sulphides during the time this portion of ore body was in the zone of secondary enrichment. As the water level moved downward, oxidation converted these secondary sulphide coatings to copper carbonates.

Gold in the ore is mostly visible in patches of porous limonite, but in two polished sections it was seen in hematite: These show that much of the gold was formerly included in the pyrite and remained behind when the latter was oxidized. Flakes of gold that occur in the copper carbonates were originally included in the tetrahedrite. One hand specimen showed a particle of gold in fresh tetrahedrite.

The galena has been altered along fractures and cleavage planes to cerussite (Figs. 4 and 6), but the latter like the hematite, is not readily visible megascopically.

Smithsonite occurs in the ore as crusts on some of the quartz. It was also observed coating sphalerite.

The mineral associations indicate that until recently oxidation has been attacking ore that has undergone slight supergene enrichment.

SUPERGENE ENRICHMENT.

The Bonanza King ore shows evidence of slight supergene enrichment and the supergene minerals covellite, chalcocite, bournonite (?), native silver, argentite, and stephanite have been recognized.

Tetrahedrite is the source of the secondary copper minerals in the deposit. It also carries some of the gold. Since the tetrahedrite contains silver, it is regarded as the source of the silver minerals, stephanite and argentite, which are seen in polished sections replacing galena along the cleavage.

Silver Minerals.—Native silver and the silver minerals, stephanite and argentite, are considered to have been derived from the tetrahedrite. Since oxidation of the silver-bearing tetrahedrite results in solution of the silver, it is logical to expect some secondary silver minerals in the deposit. Polished sections show that argentite and stephanite replace galena around its edges and along its cleavage. Argentite seems to favor the edges of the galena nodules, but stephanite more commonly replaces it along its cleavages (Fig. 4). Both silver minerals are more abundant in galena nodules in oxidized ore than they are in the fresh galena away from the fractures that carried the descending solutions. Cerussite, formed by the alteration of the galena, is intimately associated with these minerals (Fig. 4).

This mode of occurrence suggests a supergene origin for the stephanite and argentite. Emmons[21] states that stephanite is secondary in most of its occurrences and that native silver in sulphide deposits is almost invariably secondary. In the Bonanza King ore it occurs as thin flakes plastered on oxidized minerals (Fig. 7). It is probable that the silver was precipitated from sulphate solutions by ferrous sulphate.[22]

Copper Minerals.—Much of the tetrahedrite in the ore shows a film of covellite. Chalcocite can also be seen megascopically as sooty areas on some of the tetrahedrite.

[21] Emmons, W. H.: Enrichment of ore deposits. U. S. Geol. Surv. Bull. 625: 261 and 270, 1913.

[22] Emmons, W. H.: Idem, p. 270.

Polished specimens show covellite replacing tetrahedrite, galena, sphalerite (Fig. 6), and chalcopyrite. Knopf describes covellite in the supergene ore at Rochester where it forms a border around sphalerite, galena, tetrahedrite, and chalcopyrite.[23] In one instance tetrahedrite was being altered to covellite through some intermediate mineral, which as nearly as could be determined is bournonite.

Spencer [24] states that in a solution containing sulphuric acid in considerable concentration, covellite, rather than chalcocite, will be the stable mineral. Where silicate or carbonate minerals are present to take up free sulphuric acid, chalcocite will be stable. Chalcocite is more abundant than covellite in the Bonanza King ore so it is considered to be more stable. Chalcocite replaces tetrahedrite, sphalerite and chalcopyrite, but it was not observed replacing galena.

Much of the chalcocite shows a bluish-white color by reflected light. Lindgren [25] states that such bluish color is due to admixed covellite. Gilbert,[26] in his study of enrichment at Ducktown, Tennessee, found that the chalcocite was not pure but was porous and bluish-white and under high magnification the admixed covellite could be seen. Graton and Murdoch [27] have made similar observations. Spencer [28] has shown that covellite alters to chalcocite, and suggests that the change proceeds in such a way that mixtures of CuS and Cu_2S are formed. It is concluded that the bluish white material seen in some polished sections of Bonanza King ore is a covellite-chalcocite mixture.

Only the 225 foot level of the mine was accessible at the time field work was done, so that no detailed evidence of the vertical distribution of the various minerals could be obtained.

[23] Knopf, A.: *loc. cit.*, p. 47.

[24] Spencer, A. C.: Chalcocite enrichment. Econ. Geol., 8: 641, 1913.

[25] Lindgren, W.: Mineral Deposits, 4th ed., p. 839, 1933.

[26] Gilbert, Geoffrey: Oxidation and enrichment at Ducktown, Tenn. A. I. M. E. Trans., 70: 998–1023, 1924.

[27] Graton, L. C. and Murdoch, J.: The sulphide ores of copper. A. I. M. E. Trans., 45: 126–181, 1914.

[28] Spencer, A. C.: *loc. cit.*, pp. 624–630.

ORIGIN OF THE DEPOSIT.

The ore deposit was formed by hot magmatic solutions under mesothermal or hypothermal conditions. Tourmaline is the only high temperature mineral in the deposit, but it is thought that its presence is not conclusive proof of deposition at great depths.

Knopf, in discussing the genesis of the ores in the Rochester District, regards minute acicular tourmaline as having been deposited at lower temperature than the pegmatitic varieties.[29]

Buddington [30] has pointed out that high-temperature mineral deposits at moderate depths are common and to be expected. Tourmaline formed at moderate depths is commonly fine-grained and has a fine radiate, prismatic or needle-like habit. Butler, on the other hand, notes that the texture of mineral aggregates does not depend primarily on the temperature of formation but on the rapidity of supersaturation and consequent precipitation.[31]

The mineralizing solutions were probably derived from the granodiorite intrusive exposed in Spring Valley, and the Bonanza King dike is considered to be an offshoot from this intrusive mass. The dike was intruded along a fracture in Triassic volcanics. Later movement along the fracture opened the fissures through which the solutions rose and deposited coarsely crystalline quartz, largely by filling. Sulphides were deposited by replacement of the quartz. Continued movement along the vein reopened it and a second generation of quartz was deposited accompanied by the introduction of tourmaline and subordinate sulphides. Deeper faulting along the vein may have permitted the escape of higher temperature solutions that deposited the tourmaline. Thus, the bulk of the sulphides might have been deposited at a lower temperature than the tourmaline.

It is the opinion of the writer that the deposit was formed under high temperature conditions.

CORNELL UNIVERSITY,
ITHACA, NEW YORK,
Sept. 1, 1938.

29 Knopf, A.: *loc. cit.*, p. 56.

30 Buddington, A. F.: High-temperature mineral associations at moderate to shallow depths. ECON. GEOL., 30: 205–222, 1935.

31 Butler, B. S.: Discussion, high-temperature mineral associations at moderate to shallow depths. ECON. GEOL., 31: 116, 1936.

DISCUSSION AND COMMUNICATIONS

SEDIMENTARY DEPOSITS OF COPPER, VANADIUM–URANIUM AND SILVER IN SOUTHWESTERN UNITED STATES.

Sir: The article by R. P. Fischer in the November (1937) number of ECONOMIC GEOLOGY and the comments thereon by F. R. Koberlin in the June–July (1938) number are of considerable interest to Australian geologists.

Copper deposits of the red bed type are a characteristic feature of the Narrabeen Series (Lower Triassic) of East-Central New South Wales. They are strikingly like those described by Fischer. There are two main copper-bearing horizons in this sequence, neither of which can be considered as having economic importance under present conditions. In the deeper parts of the Triassic basin these beds are about 1,200 feet apart.

There has been an assumption by writers on the subject in New South Wales that there was a causal relationship between the red colour of the beds and the presence of copper, but there are definite records of copper being associated with grey-coloured sediments in the red bed horizons.

T. W. E. David[1] considered that the red beds and the copper deposits might represent the final phase of a period of vulcanicity which had been a marked feature of the Upper Permian. The presence of copper in a specimen of an Upper Permian basalt and the tuffaceous composition of the red beds were cited in support of this hypothesis.

L. F. Harper[2] later concurred in this view.

[1] David, T. W. E.: Cupriferous tuffs of the passage beds between the Triassic Hawkesbury series and the Permo-Carboniferous coal measures of N. S. Wales. Aust. Assoc. Adv. Sci., 1: 275–289, 1887.

[2] Harper, L. F.: Geology and mineral resources of the southern coal field (N. S. Wales). Mem. Geol. Surv. N. S. Wales, Geol. No. 7: 65–69, 1915.

It is no longer considered that the red beds owe their origin to volcanic agencies. They alternate with green-coloured sediments and must be considered as the normal product of cycles of prolonged dryness alternating with those of river flood plains with swamps and shallow lakes. The close association of the copper deposits with these beds suggests that the climatic factor favoured the precipitation of copper (perhaps indirectly by providing an environment suitable for the organisms presumed by Fischer tc exist). Tuffaceous sediments are common throughout the Narrabeen but the copper deposits are restricted to the two red bed horizons.

As Fischer points out, Lindgren's [3] statement that " there is no reason why the deposits should be confined to any particular geological age, but, as a matter of fact, almost all of them are in the Upper Carboniferous, Permian, Triassic or Jurassic," carries considerable implications. A recent statement by J. A. Efremov [4] concerning copper deposits of the Upper Permian in the Ural region has a bearing on this discussion. On page 36 he writes: " The large lenses of the grey ore marls were formed in more or less stable fresh water basins. The accumulation of copper salts took place syngenetically," and again on page 37, " at the same time we see that the process of formation of the ore band and cupreous salts also represents a quite definite cycle, synchronous throughout a very considerable area and apparently connected with one stage of erosion of the Urals."

These statements indicate deposition of copper salts in the sedimentary environment by some agency such as Fischer postulates. The general tenor of the description and the lithology of the associated strata appear not to admit of an origin by volcanic agency.

I do not know whether the last sentence quoted from Efremov implies a source of copper in the Ural Mountains, or how far apart the bordering lands and the sedimentary deposits are. Fischer (p. 944) mentions a distance of at least 100 miles between

[3] Lindgren, W.: Mineral Deposits, p. 404, 1933.

[4] Efremov, J. A.: Acad. des Sci. de L'Union des R. S. S., vol. VIII, pt. 1, 1937.

uplands of crystalline rocks and the carnotite deposits of south-west Colorado. In New South Wales the copper deposits are known at intervals from the basin margin for about 100 miles in the direction of maximum deposition. The surrounding terrain of pre-Permian rocks contains many small vein copper deposits that are regarded as the ultimate source of the copper in the Triassic sediments.

H. G. RAGGATT.

GEOLOGICAL SURVEY OF NEW SOUTH WALES,
SYDNEY, N. S. WALES,
October 26, 1938.

REVIEWS

Gold Deposits of the World. By WILLIAM HARVEY EMMONS. Pp. vi + 562; figs. 332. McGraw-Hill, New York, 1937. Price $6.00.

In a period when nearly all the other products of the mineral industry have been quoted at prices close to their all-time lows, because suffering under-consumption in a world economically demoralized, the facts that gold is selling for the highest price in its history and at the same time is being produced at a rate never before equalled naturally create an acute interest in known gold-bearing regions and in the possibilities of discovering new ones. This book by a mining geologist of high standing is therefore well timed and is sure to attract wide-spread attention. The "Section on Prospecting" announced in the sub-title broadens the circle of appeal and at the same time confirms the presumption from the main title that the view-point is primarily geological. Indeed, the treatment proves to be so definitely professional that it will probably awake far more response among economic geologists and perhaps to some extent among prospectors than in the general reader or those interested in the various aspects of the economy of gold.

The book comprises two quite different portions: Chapters II–VII, 500 pages, devoted to descriptions of individual deposits or districts, arranged by continents and countries; and Chapters I and VIII, 45 pages, dealing with certain geological generalizations about gold deposits. Different readers will appraise these two portions variously, but the majority may conclude that the relative importance is more or less commensurate with the space devoted to each.

The descriptive portion represents enormous labor. Some 1400 localities are listed in the index, and most of these are independent areas. Citations to the literature run into the thousands from a surprisingly wide range of sources and, although of uneven completeness from district to district, constitute one of the most valuable features of the work. Valuable also are the numerous maps showing geographic positions of districts. Since so much of the material has had to be derived from what is available in the published literature, its up-to-dateness, thoroughness, reliability and insight are necessarily highly variable; the compiler has little control over the balance of emphasis, and must inevitably reflect the fact that, for most occurrences, economic rather than scientific importance

largely determines the volume and to some extent the quality of the information.

The key to such flavor as the author has deliberately and consistently imparted to the whole is found early in the preface: that most hypogene gold deposits are genetically associated with granitoid batholiths and bear relatively restricted positional relationship to the margins of those masses. Both these subjects have long engaged the interest and thought of the author, and the present volume may be regarded as culminating the evidence which his various earlier writings have brought to their support. The present assemblage places under these ideas a far better quantitative foundation than has hitherto existed, and leaves little doubt as to their general validity, though many skeptically minded mining geologists may still be unwilling to accept even these widely held concepts in such boldly simplified and idealized form. Not so convincing is the treatment of the subject standing next in emphasis received, supergene enrichment of gold, another of the author's long-standing interests. After this marshalling of whatever specific evidence there may be, many may continue in the view that the solution, migration, and concentration of gold by chemical processes in the superficial zones is a relatively rare and unimportant phenomenon, especially inasmuch as the logically-expectable overlying zone of leaching is almost never to be found. It must be admitted that the behavior of gold in croppings under varied physiographic and climatic conditions as well as varied rock and mineral environment is by no means definitely and precisely known, but in the reviewer's opinion many if not most of the conspicuously rich shallow gold occurrences may be adequately explained either as residual enrichments or as extreme manifestations of vertical hypogene zoning.

As compared with these particular topics, others nearly or quite as significant geologically frequently receive relatively subordinate and perfunctory attention. From what the literature affords, several hundred drawings of maps and sections of regions and mines have quite obviously been selected primarily to illustrate the batholith-margin idea—and necessarily range from good to bad, as is characteristic of maps and sketches published here and there, some based on years of careful work and some on hours, by men of widely differing competence. Without more critical appraisal of their relative worth, these illustrations give to the book an air of uncontroversial soundness which their quality does not invariably support; and they are not balanced by a single photograph of vein structure, of microscopical texture, or of mineral relationship. Structural details, of the sort with which mining geologists are more and more concerned, receive relatively scant attention, either in diagrams or in the text. One regrets the inclusion of many drawings and descriptions of districts of very little significance, at least as far as gold is concerned, and of the

many scattered wisps of information, such as the lines about Great Bear Lake, Huachon or Seven Devils if these be the cause of the brevity of treatment of many features of higher worth, as, for example, the enormous residual concentration of gold with sandy barite beneath the gossan at Kyshtim, which is merely mentioned. For the most part the published accounts, like the maps, are accepted at face value, and even conflicting views presented with editorial impartiality. The reader could well wish that the author had much more frequently ventured to loose his own vigorous analysis as he has, indeed, done so effectively in certain instances, notably the Rand district.

The book opens with a conventional treatment of the gold minerals and proceeds, after classifying gold deposits, with condensed statements on supergene enrichment, formation of placers, mineral associations in gold ores, and metallogenetic provinces and epochs, in the course of which is made a brief but effective negation of the growth of gold nuggets and of recrystallization of gold in deep deposits. The remainder of the first chapter and most of the last deal with the positional and broadest structural relations of gold ores to batholiths—which could most fittingly have been made the title of the volume. The various deep-levels in the supposed ideal batholith and their respective probabilities of containing ore deposits, the concepts of "hood" and "dead-line," the relation of fractures in strike and causation to associated batholiths and other stimulating ideas that have been presented in the author's earlier writings are here forcefully summarized, but with a zealousness which leads to unconvincing extremes. In many of the conclusions it would seem that every relationship has been resolved in the desired direction through sheer faith in the rightness of the basic theses. For instance: "In these (shield) areas which supply a large part of the world's lode gold, the relations are as follows: Gold production from invaded rocks and from intruding rocks within a mile of contact, 99.9 per cent." Such a snappy quantitative sentence is precisely the kind that general text-book writers pounce upon and perpetuate. If such a statement implies that this percentage of gold has been won from deposits within a mile of the contact of the genetically responsible intruding rocks, it is open to serious criticism. It may be so, but surely the production from districts in which the source of gold is still obscure far exceeds one tenth of one per cent.

The interesting case made for the tendency toward radially-disposed fractures about stocks of circular plan and toward general correspondence between strike of fractures and major axis of elongated stocks would probably be more widely persuasive if accompanied by adequate consideration of the numerous exceptions and by some discussion of other causes of fracturing than the one favored, viz., vapor pressure generated as the batholith cools and crystallizes. Little fault should be

found with the idea that many vein-carrying fractures are of tensional character and probably were caused by pressure in the magma that now constitutes a near-by stock; but there seems little compelling evidence that this pressure originated or was applied primarily as "vapor pressure," nor that the reason for greater abundance of fractures associated with the high points or cupolas of the intrusive is so much due to alleged greater accumulation of gases there (for this magma-gas combination should constitute a *fluid* system with essentially equalized pressures) as because at these shallowest points the overlying cover would be weakest toward *any* magma-originating pressure. Nor should it be overlooked that very many veins, whether gold-bearing or otherwise, occupy fractures which, though equally closely timed to the associated intrusive, are definitely not of tensional origin but both by orientation with respect to other structures and by inherent characteristics show that they are the immediate result of compression and shear.

But whether sound or not, the proposals are surely worth thinking about; and it is in just this way that the science of geology matures. More regrettable is what the book does not contain. This heavy investment of time and thought afforded a rare opportunity for assembling the major generalizations regarding the geology of gold in a much more comprehensive way. The particular relationships which the author is content to emphasize are indeed important but afford a very restricted view of gold deposits in general. The genetic classification on page 4 might well have been expanded from the few examples mostly known to everyone into a tabulation of all gold deposits for which the necessary data exist. Tables as to age, wall-rock, structural type, etc. would have been valuable additions, especially if more complete as to districts than the mineral chart on page 36, and more like the listing of batholithic relations which is the chief contribution of the chapter on Prospecting. It would have been profoundly illuminating to have the condensed and analyzed testimony of 1400 districts on such fundamental questions as size, shape, attitude and persistence of ore shoots; and the controls on richness exerted by kind of wall-rock and by structure, as well as by mineralogy and texture of the pre-gold minerals. Even for secondary enrichment there is no list of examples in either text or index. Perhaps this indefatigable producer already has in hand another volume on gold which will serve to generalize more comprehensively from the details given in the present one.

In appraising this imposing treatise on gold deposits comparison instinctively arises with those other two, respectively by Maclaren and by Dunn. To the latter it is immeasurably superior both in completeness and in soundness of concept as measured by modern geological standards. It has the inevitable advantage of thirty years' growth in fact and theory

since Maclaren. That free-lance geologist devoted long years to gain direct contact with the deposits of many lands; this explains the verve and the indefinable insight into what gold ores really are that characterized his volume. The essence of Emmons' method, here as in earlier contributions, is to bring support to a central idea by analysis of the literature; whereas Maclaren depended to a greater extent on the field relations as he saw them in the many mines which he examined. Until someone handles the subtle realities of the field and the accumulated records of the library with equal mastery, a book better than these very different volumes can hardly be expected. The extent to which the author's own rich background of field experience and power of penetrating thought is brought to bear on the assemblage of data determines the worth of the book beyond its substantial value as a comprehensive compilation; and by this measure many parts of it are indeed stimulating additions to our literature on ore deposits, even though the book may fail to attain the consistently high level expected in contributions from so able a scientist.

L. C. GRATON.

LABORATORY OF MINING GEOLOGY,
HARVARD UNIVERSITY,
CAMBRIDGE, MASS.,
Nov. 10, 1938.

The Properties of Glass. By G. W. MOREY. Pp. 561, Figs. 20. Reinhold Publishing Corporation. New York. Cloth. Price $12.50.

This monograph, sponsored by the American Chemical Society, is designed to present the knowledge of glass available to students of this material and to promote research on the topic by "furnishing a well digested survey of the progress already made and by pointing out directions in which investigation needs to be extended." All measurements on glasses of known composition are quoted and through the discussion the emphasis has been placed on their physical properties as functions of composition. The thoroughness with which the field has been covered is indicated by the 781 literature references that have been cited in summarizing the information contained in the volume.

The book is a condensed summary of all the facts known concerning glass, including its history, its devitrification, composition, and durability, as well as a discussion of its physical properties, especially its viscosity, surface tension, heat capacity and conductivity, its density, its coefficient of expansion, its elastic, optical and magnetic properties, its density, strength, hardness, its thermal endurance and its electrical conductivity. All these properties are correlated with its composition, particular emphasis being given to the effects of its individual components upon them.

The final chapter summarizes the views of various students upon the constitution of glass.

The book is so packed with data dealing with glass that it may serve as a handbook not only for glass technologists, but also for geologists who have to deal with glassy volcanic rocks and the properties of their magmas. Its style is so compact and its discussions are so closely interwoven with graphs that it is not adapted to the use of non-technical readers, but it is practically essential to those who are interested in the scientific study of both natural and manufactured glasses.

It is unnecessary to state that its information is authoritative. Its author's name guarantees this.

W. S. BAYLEY.

About Petroleum. By J. G. CROWTHER. Pp. xiv + 181. Pl. 14, Figs. 10. Cloth, 5¾ × 8¾. Oxford University Press, London and New York, 1938. Price $2.25.

This is a handy little book telling to inquisitive laymen the major known facts about the sources and utilization of petroleum, its chemical nature, the methods involved in discovering its hidden stores, its refining and an outline of the processes employed in the manufacture of its substitutes. It is a sort of summary for non-technical readers of the well known treatise "The Science of Petroleum." The chapters on finding oil and well drilling are especially acceptable, as well as those on "Petroleum and its colloids," "cracking" and "hydrogenation."

The book is well written in non-technical language, is authoritative, and well illustrated and is provided with a satisfactory index.

W. S. BAYLEY.

Outline of Historical Geology. By A. K. WELLS. Pp. xiv + 266. Pl. 2. Figs. 99. Geo. Allen & Unwin, Ltd., London, 1938. Nordemann Pub. Co., Inc., N. Y. $3.50.

The historical aspect of geology is regarded by the author as of high cultural value and consequently he offers this little book in "an effort to cater for the requirement of the general reader who is not content to remain in ignorance of the history of his country prior to the year 55 B.C." He writes only for British readers, since his discussion is limited to the geology of the British Islands. The book is well written and because it avoids technicalities it should be easily read by those for whom it was intended. Unfortunately, it is of little value to the American reader since it makes no reference to phenomena exhibited outside of Great Britain, nor to any but British stratigraphic nomenclature. For instance

no mention is made of the words Mississippian or Pennsylvanian. However, the general principles involved in stratigraphic philosophy are clearly explained.

W. S. BAYLEY.

Metalliferous Deposits of the Cascade Range, Oregon. By E. CALLAGHAN AND A. F. BUDDINGTON. Pp. 141; pl. 22; figs. 7. U. S. Geol. Surv. Bull. 893. 1938. Price, $1.25.

This is a valuable systematic survey of the mineral deposits of a large region. The rock formations and structure are carefully described. The deposits are Tertiary epithermal veins of base metal and gold related to dioritic intrusives. The individual deposits are concisely described.

Lexicon of Geologic Names of the United States. 2 vols. COMPILED BY M. GRACE WILMARTH. Pp. 2396. U. S. Geol. Surv. Bull. 896. Supt. of Documents. Washington, 1938. Price $2.50.

This comprehensive and exhaustive compilation has been prepared over a period of 25 years; includes the names and ages of all named geologic units in the United States, Alaska, Canada, Mexico, Central America, West Indies and Hawaii. Each includes briefly the lithology, thickness, age, underlying and overlying formations, type locality, and definitions of United States names. Replaced formational names are indicated. The two volumes are indispensable to geologists.

BOOKS RECEIVED.

J. D. BATEMAN.

Cambrian System (Restricted) of the Southern Appalachians. C. E. RESSER. Pp. 140; pls. 16. G. S. A., Special Papers, 15, 1938. *Definition and correlation of Southern Appalachian Cambrian formations.*

Geophysical Abstracts No. 91, October-December, 1937. W. AYVAZOGLOU. Pp. 66. U. S. Geol. Surv. Bull. 895–D, 1938. Price, 15 cts. *Brings Bull. 885 up to date.*

Geology of the Superficial Coastal Deposits of British Guiana. D. R. GRANTHAM AND R. F. NOËL-PATON. Pp. 122; fig.; map. Brit. Guiana Geol. Surv. Bull. 11, Georgetown, 1938. Price, $1.00. *Bauxite, gold, diamonds.*

Simard (Expanse) Lake Map-Area, Témiscamingue County. B–. T. DENIS; **Suzor-Letondal Map-Area, Lavoilette, Saint-Maurice and Abitibi Counties.** C. FAESSLER; **Bruneau Township and Surrounding Area, Abitibi District.** G. V. DOUGLAS; **Grevet (Kamshigama Lake) Map-Area, Abitibi District.** W. W. LONGLEY. Pp. 80; figs. 14; pls. 8; geol. maps, 3. Quebec Bur. Mines Ann. Rept., 1936, pt. B, Quebec City, 1937. *Regional geology of gold-bearing areas.*

Soil Erosion and Water Supplies in Uganda. E. J. WAYLAND AND N. V. BRASNETT. Pp. 89; figs. 5; pls. 6; geol. map. Uganda Geol. Surv. Mem. 4, Entebbe, 1938. Price, 7/50. *Practical report with conservation recommendations.*

Geology of the Lower Umfuli Gold Belt, Hartley and Lomagundi Districts, Southern Rhodesia. A. E. PHAUP AND F. O. S. DOBELL. Pp. 150; pls. 11; geol. map. South. Rhod. Geol. Surv. Bull. 34, Salisbury, 1938. Price, 5/–. *Small pre-Cambrian gold deposits.*

Vermiculite Deposits in the Palaboroa Area, Northeast Transvaal. C. M. SCHWELLNUS. Pp. 25; figs. 5. Union of South Africa Geol. Surv. Div., Bull. 11, Pretoria, 1938. Price, 6d. *Vermiculite deposits of economic importance in pyroxenites and serpentines.*

Petrology of the Pennsylvanian Underclays of Illinois. R. E. GRIM AND V. T. ALLEN. Pp. 29; fig., pls. 2. Ill. Geol. Surv. Rept. of Invest. 52, Urbana, 1938. *Reprint from Bull. G. S. A., vol. 49, pp. 1485–1514, 1938.*

Geology and Coal Resources of the Southeastern Kansas Coal Field. W. G. PIERCE AND W. H. COURTIER. **Pennsylvanian Invertebrate Faunas of Southeastern Kansas.** J. WILLIAMS. Pp. 122; figs. 13; pls. 11; geol. map. Kan. Geol. Surv. Bull. 24, Lawrence, 1937. *Contribution to the knowledge of Lower Pennsylvanian.*

Geology and Oil and Gas Resources of Rush County, Kansas. K. K. LANDES AND R. D. KEROHER. Pp. 31; figs. 4; pls. 2. Kan. Geol. Surv. Min. Res. Circ. 4, Lawrence, 1938.

The Geology of the North Ilunga Area, Tanganyika. A. C. SKERL AND F. OATES. Pp. 38; pls. 2. Tanganyika Geol. Div. Short Paper 18, Dar es Salaam, 1938. Price, 3/–. *Igneous petrography.*

A Summary of the Uses of Limestone and Dolomite. J. E. LAMAR AND H. B. WILLMAN. Pp. 50. Ill. Geol. Surv., Rept. of Invest. No. 49, Urbana, 1938.

Potential Markets for Illinois Coal on the Upper Mississippi Waterway. W. H. VOSKUIL. Pp. 19; figs. 2. Ill. Geol. Surv., Circ. No. 41, Urbana, 1938.

Contributions of the Fifth Annual Mineral Industries Conference. Pp. 240; figs. 44; pl. Ill. Geol. Surv., Circ. No. 23, Urbana, 1938. *Numerous papers concerning recent scientific and industrial developments significant to the mineral industries of Illinois.*

Spores from the Herrin (No. 6) Coal Bed in Illinois. J. M. SCHOPF. Pp. 73; figs. 2; pls. 8. Ill. Geol. Surv. Rept. of Invest. No. 50, Urbana, 1938. *Systematic descriptions; classification of spores.*

Recent Petroleum Development in Illinois. A. H. BELL AND G. V. COHEE. Pp. 9; figs. 4. Illinois Petroleum, No. 32, Urbana, 1938. *Studies indicate reserves in new areas in excess of 100 million barrels.*

Oil and Gas Development in Illinois in 1937. A. H. BELL. Pp. 19; figs. 2. Illinois Petroleum, No. 31, Urbana, 1938. *Daily production of petroleum trebled during year.*

Carbonizing Properties and Petrographic Composition of Upper Banner Bed Coal from Dickenson County, Virginia, and Vigo County, Indiana. A. C. FIELDNER, J. D. DAVIS, R. THIESSEN, W. A. SELVIG, D. A. REYNOLDS, R. E. BREWER AND G. C. SPRUNK. Pp. 81; figs. 52. U. S. Bur. Mines, Tech. Paper. 584, 1938. Price, 10 cts. *Also effect of blending these coals with Beckley Bed coal.*

Geology of the Baguio Gold District, Philippines. ANDREW LEITH. Pp. 91; figs. 5; pls. 3; geol. map. Geol. Surv. Div. Tech. Bull. 9, Manila, 1938. *General geology and ore deposits.*

Illinois Mineral Industry in 1937. W. H. VOSKUIL, ALMA R. SWEENEY AND G. N. OLIVER. Pp. 50; fig. Ill. Geol. Surv., Rept. of Invest. No. 51, Urbana, 1938.

Les Séries de Szipot dans les Karpates Polonaises Orientales. ZB. SUJKOWSKI. Pp. 105; figs. 18; pls. 14; geol. map. Travaux du Service Géol. de Pologne, vol. 3 liv. 2, Warsaw, 1938. *A geologic and petrographic study of part of the Flysche; numerous excellent photomicrographs; text in Polish, French abstract.*

Some Arizona Ore Deposits. Pp. 136; figs. 12; pls. 4; maps, (supplement) 36. Ariz. Bur. Mines, Geol. Ser. 12, Bull. 145, Tucson, 1938. *Contributions by 15 eminent geologists and mining engineers dealing with many important districts including Miami-Inspirtation, Bisbee, Jerome, Clifton-Morenci, Ray and Ajo.*

Bulletin of the Geological Service of Poland. Vol. 9, No. 2. Pp. 234; pls. 8; figs. 14. Warsaw, 1938. *Papers in Polish on paleontology, structural and stratigraphic geology followed by abstracts in German or French.*

Prospecçao Magnetica no Norte de Santa Catharina. M. C. MALAMPHY, H. C. A. DE SOUZA AND I. C. DO AMARAL. Pp. 22; figs. 23; maps, 2. Serviço Geol. E Min., Bull. 85, Rio de Janeiro, 1937. *Results of magnetic geophysical methods.*

Compte-rendu des Recherches du Minerais de Manganèse sur le Pretuczny dans les Monts Czywczyn (Karpates Polonaises Orientales). R. KRALEWSKI. Pp. 28; fig.; pls. 3. Inst. Géol. de Pologne, Bull. 2, Warsaw, 1938. *Text in Polish, French abstract.*

Activité de l'Institute Géologique de Pologne en 1937. Pp. 41. Inst. Géol. de Pologne, Bull. 1, Warsaw, 1938. *Text in Polish; French abstract.*

Quelques Reflexions sur la Tectonique du Socle Cristallin de la Tatra. F. RABOWSKI. Pp. 9; figs. 2. Inst. Géol. de Pologne, Bull. 4, Warsaw, 1938. *Text in French.*

O Massiço do Itatiaya e Regiões Circumdantes. A. R. LAMEGO. Pp. 93; figs. 42; map. Serviço Geol. E Min., Bull. 88, Rio de Janeiro, 1938. *Regional geology.*

Lagos Duas Bôcas E Novo. J. BORGES. Pp. 23; figs. 9. Serv. Geol. E Min. Bull. 87, Rio de Janeiro, 1938.

SOCIETY OF ECONOMIC GEOLOGISTS

Abstracts of papers to be presented at the Nineteenth Annual Meeting in Conjunction with the mining geology section, American Institute of Mining and Metallurgical Engineers, New York, Feb. 14–16, 1939.

*THE QUICKSILVER DEPOSITS OF THE TERLINGUA REGION, TEXAS.**

C. P. ROSS.

Texas is second among quicksilver-producing States because of the Terlingua region, in the Big Bend of the Rio Grande. This region contains Cretaceous strata, largely calcareous, which pass upward into Tertiary volcanics. The strata are cut by numerous intrusions, largely alkalic; and are extensively folded and faulted.

Many of the lodes are near the base of the impervious Del Rio clay, some at higher horizons, and a few in intrusive masses. The solutions penetrated only along open passageways, such as major joint openings in zones of tension, and, especially at horizons above the Del Rio, in fractures related to fault zones.

The quicksilver is believed to have been brought in in alkali sulphide solutions with free alkali. Most other constituents that may once have been present in the solutions had been separated earlier. Precipitation resulted largely from mingling with groundwater that must have contained free carbonic acid, as it had dissolved limestone extensively. The comparatively low temperature and pressure at the shallow levels where groundwater was present aided the precipitation. As the then-existing zone of groundwater circulation has since been cut into by erosion, the lodes are necessarily rather close to the present surface. The gangue minerals, particularly the calcite, are believed to have come from the sedimentary rocks with rearrangement and some addition of material from deep sources. The relation of the widespread bitumen to genesis is puzzling here, as in many other quicksilver deposits. Weathering is of slight economic importance. Many minerals that resemble supergene products, including the quicksilver chlorides, are thought to have resulted here from original deposition within the zone of vadose water.

GEOPHYSICS SUPPLEMENTING GEOLOGICAL EXAMINATIONS.

HANS LUNDBERG.

Considerable experience has been accumulated from geophysical surveys on different geological formations, in different climates and on

* Indicates that abstract is published by permission of the Director, *Geological Survey*, U. S. Department of the Interior.

different types of ore deposits. Under favourable conditions it is now possible to study geological formations and to follow geological contacts where the bed rock is hidden from view.

This paper briefly reviews the factors that are utilized in identifying various rock types. Some examples of geophysical results are given and although this work is still an art, it is hoped that soon the methods will become so well known and so easy to handle that they can be generally utilized by the geologists.

*PRELIMINARY REPORT ON THE ORE DEPOSITS OF THE CHICHAGOF MINING DISTRICT, ALASKA.**

JOHN C. REED.

This paper deals briefly with some of the principal results of 3½ months' field work during the summer of 1938 in the Chichagof mining district, southeastern Alaska. This report is be followed later by a more complete report to be published by the Geological Survey. The paper is concerned principally with the structural geology of a block of steeply-dipping graywacke as revealed underground in the Hirst Chichagof and the Chichagof mines, the two principal mines of the district, which have produced about $16,000,000 worth of gold and silver.

The attitude of the graywacke, which is locally cut by dikes and sills of aplite, is remarkably uniform and trends about N. 62° W. The average dip is about 67° S.W.

The graywacke is cut by large faults, the best known of which are the Hirst and the Chichagof faults, whose average trends are about N. 30° W., and whose average dips are about 75° S.W. The faults at some places split into the bedding of the graywacke and at other places are deflected from their normal trends for considerable distances along the bedding. The relative movements along the faults was northwest and up at about 30° for the southwest or hanging wall sides.

The ore bodies are elongate quartz lenses in the faults. Most of the quartz is mineralized but locally large quartz masses are too low grade to be mined.

The emplacement of the ore bodies appears to have been structurally controlled in large part by the intersections of the faults with the bedding surface. Places where the faults split or are deflected appear to have been particularly favorable places for ore deposition.

There have been some post-quartz movements along the faults but it is thought that such movements have not been extensive enough to greatly modify the original positions and shapes of the ore bodies.

ANTHRACITE DEVELOPMENT IN THE CRESTED BUTTE DISTRICT, COLORADO.

E. C. DAPPLES.

Effects of factors such as temperature, pressure, and vegetable composition that were considered dominant in the formation of anthracite were studied in the Anthracite-Crested Butte Quadrangles, Colo. The district is one of gently dipping Cretaceous strata containing coal beds that have been intruded by large laccolith-like masses of quartz monzonite.

Negligible metamorphism of the strata, dense groundmass, and zoning of plagioclase suggest low temperatures (900° C.) of the intruding rock. Strata ranging from 6,700 to 17,000 feet covered the intrusions. Temperatures attained by the Ruby anthracite 300 feet above the igneous rock are calculated to have ranged from 290°–350° C. Coal subjected to shearing or compression stresses advances in rank if heated to temperatures approaching 300° C. If not subjected to stress the coal cokes. Likewise if the coal is subjected to stress without attaining temperatures near 300° C., the coal fails to increase in rank unless mass fracturing of the coal occurs; friction along the fracture planes raises the temperature sufficiently for anthracitization.

GEOLOGIC PARALLELS: HOG MOUNTAIN, ALABAMA AND PARACALE, PHILIPPINE ISLANDS.

EWARD WISSER.

The comparison of mining districts is stimulating and often fruitful in the study of ore deposits. A pair of districts showing abundant significant resemblances suggests common causes for the like features. Gaps in the picture of one district may be filled out from knowledge of the analogous district. A third district may show some features common to the first two, but other characteristics not shared by the first two districts. These other characteristics may be shown in a fourth district, having nothing else in common with the first three. Study of all the districts may lead to the forming of generalizations that explain the presence or absence of a given feature in any one of the four districts. It is thus that the knowledge of ore deposits in general is advanced.

The Hog Mountain and Paracale districts resemble each other in the following features:

1. An elongated granitic mass, intrusive into the surrounding rock, which is schist.
2. Steep-dipping veins striking perpendicular to the major axis of the intrusive mass.
3. Abrupt ending of the veins at the schist-granite contact; some widening of the veins and localization of ore at the contact where the vein ends.
4. Poor mineralization along the contact itself.
5. Veins predominantly replacement, partly filling of preexisting fissure.
6. Slight tectonic movements during mineralization, but main regional deformation was ended by the time of mineralization.
7. Gold veins, with little silver.

Based on the above resemblances, an origin for the Hog Mountain veins is suggested from study of the Paracale district. This origin differs from any hitherto advanced.

THE GEOLOGY AND DEVELOPMENT OF THE POLARIS–TAKU MINE.

D. C. SHARPSTONE.

Polaris-Taku, British Columbia's most northerly producing lode gold mine, lies 38 miles east of Juneau, Alaska. Production, starting in Nov.

1937, was attended by unusual and complicated metallurgical, geological and transportation problems. The property is accessible by river boat and road during the summer, and is serviced by airplane from November to May.

Arsenical ores occur in a complex system of faulted veins within volcanic greenstone walls, and are mined and milled in excess of 200 tons daily, concentrates being shipped to Tacoma.

Veins ranging from a few inches to 25 feet in width occur: (1) near and along contacts between competent and incompetent volcanic types and, (2) along cross fissures in competent massive volcanics. Mineralization is gold, arsenopyrite, pyrite and minor stibnite in quartz and carbonates. Successive periods of mineralization are evident. Gold and arsenopyrite were deposited early and are intimately associated and closely interlocked. A little gold may occur with pyrite, negligible quantities are free. The deposits are probably mesothermal.

A STUDY OF THE HEDLEY MILL PRODUCTS.

HARRY V. WARREN AND C. MADSEN.

This paper briefly outlines the results obtained by studying the mineralogy and mill products of the Hedley Nickel Plate Mine. In this study the authors have used the Haultain Infra-Sizer and Super-Panner and achieved results which could not have been obtained without these tools. The net result of these tests has been to indicate the possibility of increasing recovery by obtaining a finer grind, particularly of arsenopyrite. The company has graciously intimated that it will be pleased to give out to interested parties, pertinent information on the steps they are taking to achieve these ends.

EXPERIMENTAL STUDY OF SOME PHYSICAL CHARACTERISTICS OF CERTAIN ORE-BEARING LIMESTONES.

OLAF N. ROVE.

Specimens of the various ore-bearing limestones from a half dozen different mining camps were procured through the coöperation of operating companies and their staffs. These specimens were tested as to permeability, impact member, crushing strength, and relative grindability in an effort to correlate these data with the relative importance of the horizon as a known ore-bearing limestone in the respective districts. The data do not reveal any consistent correlation, nevertheless several interesting relationships are suggested, which would seem to warrant a more detailed study of some single district.

PRELIMINARY ACCOUNT OF THE GEOLOGY OF A PORTION OF THE LUPA GOLDFIELD, TANGANYIKA, AFRICA.

DAVID GALLAGHER.

The paper is based on work still in progress, which is the first detailed geological study that has been made in this new goldfield. The general geology is briefly described, together with the available factual data regarding the nature and origin of the lenticular gold quartz veins.

These are abundant throughout the region, and their structure and simple mineralogy indicate that they are of the deep zone type. It is concluded that the mineralization is genetically related to a widespread invasion of the region by alaskite.

SALT WATER INTRUSION: A COASTAL GROUND-WATER PROBLEM.

HENRY C. BARKSDALE.

Salt water intrusion is defined for the purposes of the paper as the upward movement of salt water caused by an artificial lowering of the fresh-water head in water-bearing beds containing both fresh and salt water. Although the principles involved are generally applicable, the discussion is confined largely to the intrusion of salt water into Coastal Plain formations. The principle of Baydon Ghyben and Herzberg is discussed with theoretical applications to conditions that might occur along the coast of a body of salt water. The discussion of the theory is illustrated with descriptions of the intrusion of salt water into water-bearing beds in New York, New Jersey and other coastal areas. It is pointed out that detailed study, long-range planning, and effective control of the withdrawal of ground waters are necessary if salt-water intrusion is to be avoided in many important water-bearing formations.

*DISCONTINUITIES OF THE MINERAL SEQUENCE IN THE SAN JUAN MINING DISTRICTS, COLO.**

W. S. BURBANK.

The mineral sequences considered belong, in part, to ores associated with early Tertiary laccolithic centers of the western San Juan and in part, to those associated with late Tertiary volcanic centers. The deposits belong to the upper mesothermal (leptothermal) and epithermal zones. Many veins contain both base metal and precious metal shoots, and, beginning with the geologic work of Purington in the late 90's, the compound nature of the veins has been emphasized. This paper emphasizes more particularly the possible genetic significance of the compound mineralogy. Three principal features or incidents commonly interrupt the continuity of deposition of the minerals of the veins—(1) pre- and intermineral clastic injections; (2) pre- and intermineral leaching; and (3) mineralogical discontinuities characterized by abrupt or significant changes in the introductory minerals of a suite or stage. Both from structural evidence and from theoretical considerations, all three classes of discontinuities appear to result from relatively abrupt changes of pressure upon the solutions or their sources. The mineral discontinuities of class three are divisible into several distinct suites or stages, which, in the order of their zonal and time relationships, are (1) an iron oxide (specularite) and ferric silicate suite; (2) a complex manganese silicate suite; (3) a barite suite; and (4) a fluorite suite. With the common exception of the fluorite stage, each is accompanied by the more common base metal sulphides, but in different proportions. Thus, pyrite decreases from early to late stages, and it may be absent in the fluorite

stage. The common sulphides accompany chiefly the iron and manganese silicate stages, whereas the lead-silver and gold ores accompany the barite and fluorite stages. The basic order of the mineral stages is believed related to processes of progressive oxidation at the sources. There is a special suite, represented by the kaolin group, alunite, and other associated minerals, that characterizes shallow-source mineralization. Possible genetic classifications of the different phenomena are considered briefly.

*MANGANESE IN A THERMAL SPRING DEPOSIT IN WEST-CENTRAL UTAH.**

H. E. THOMAS AND EUGENE CALLAGHAN.

A small amount of manganese ore has been shipped from a hot spring deposit in Juab County, Utah, about 20 miles north of Delta. The hot waters (up to 180° F), issue from a dome about one-quarter mile wide and twenty feet high on the gently sloping plain that was once the bottom of Pleistocene Lake Bonneville. The dome, which is near the margin of a pre-Bonneville basalt flow, is composed of hard spring deposit and wind-blown sand. Most of its surface has a marshy coating of wind-blown material, in part cemented by salts from the spring waters. Quarries and ditches expose the deposits, which consist chiefly of porous calcite with lenticular ferruginous and manganiferous beds. A sample of the best-appearing manganiferous bed 1.1 feet thick was analyzed in the chemical laboratory of the Geological Survey and was found to contain 42.92 per cent MnO, 17.93 per cent Fe_2O_3, 5.50 per cent CaO, and 4.28 per cent BaO. At present the hot waters appear to be depositing only calcium carbonate, and two incomplete analyses of the water show a preponderance of chloride, sulphate, calcium, and bicarbonate, in descending order of abundance, with no manganese in one sample and 0.3 parts per million in another. Evidently, some substances, such as manganese, were deposited in abundance only in certain stages in the history of the spring.

STRUCTURAL RELATIONS OF CHROMITE DEPOSITS.

EDWARD SAMPSON.

The following structural types are proposed: Evenly scattered, Schlieren banded, Stratiform, Sackform, Fissureform.

Evenly scattered.—Accessory grains, commonly corroded. Widespread.

Schlieren banded.—Grains concentrated in bands, either massive, or more commonly scattered grains. Boundaries of bands commonly gradational. Kenai Peninsula, Alaska; Black Lake, Quebec; Skoplji, Yugoslavia.

Stratiform.—Occur in highly differentiated sheets or lopoliths. Persistent zones of chromite-rich rocks. In detail, zones composed of multiple impersistent bands. Bushveld, Union S. Africa; Great Dike, S. Rhodesia; Stillwater complex, Montana.

Sackform.—Irregularly rounded ore borders, commonly of nearly pure chromite. The chromite grains usually interlocking. Boundaries of ore bodies commonly sharp. Selukwe, S. Rhodesia; Skoplji, Yugoslavia; Unst, Shetland Islands; Wood's Mine, Pennsylvania.

Fissureform.—Tabular masses lying along fissures. Black Lake, Quebec; Selukwe, S. Rhodesia; Orascha, Yugoslavia.

ORIGIN AND DIFFERENTIATION OF THE MAJOR ACID INTRUSIVES OF THE ROUYN-BELL RIVER AREA, NORTHWESTERN QUEBEC.

WILLIAM CARRUTHERS GÜSSOW.

The intrusives in question are all pre-Cobalt in age and are later than the post-Timiskaming folding. In other words, they are all limited to the so-called Algoman period of igneous activity.

The various phases of these plutonic masses have been mapped and were described in an earlier paper. Petrographic examination and chemical analyses indicated that few are true granite and suggested that several are differentiates of a common magma.

This paper deals with the general age of the intrusives, their origin, and possible course of differentiation. It is shown by means of variation diagrams that the earlier conclusions arrived at were justified and that a common magmatic stem is indicated for the various phases of the Bourlamaque, Taschereau, Palmarolle, and Flavrian masses. The Bourlamaque mass, originally a quartz-gabbro, was first injected, and was followed by the tonalites and granodiorites of the other masses. Magmatic solutions, presumably from the same source, locally altered the Bourlamaque quartz-gabbro to an albite-tonalite.

A table of 26 Rosiwal analyses is appended bringing up to date all available information on these intrusives.

A NICKEL DEPOSIT NEAR GOLD HILL, COLO.*

E. N. GODDARD AND T. S. LOVERING.

Recent development in the Copper King mine, near Gold Hill, 8 miles northwest of Boulder, Colo., has opened a nickel deposit in the pre-Cambrian rocks of the Colorado Front Range, the second of its kind known to exist in this region. The deposit occurs in highly metamorphosed sediments of the Idaho Springs formation, one-half mile west of the border of a small batholith of mid-pre-Cambrian granite. A small stock of hornblende diorite, related to the granite, is exposed in the lower workings and numerous irregular pegmatite dikes cut the schists, gneisses, and lime-silicate rocks of the Idaho Springs formation, which have been folded into a tight anticline.

Disseminated intergrowths of pyrite, pyrrhotite, chalcopyrite, pentlandite, and niccolite have replaced amphibole in the more calcic beds of a lime-silicate layer in the Idaho Springs formation. Numerous samples of the primary ore taken by the company yielded from 0.41 to 6 per cent nickel, 0 to 0.60 per cent cobalt, and small amounts of copper. Samples of supergene ore contained from 1.32 to 13.02 per cent nickel, 0.22 to 6.22 per cent cobalt, and 0.05 to 31.60 per cent copper. There appear to be several thousand tons of ore in sight that contain from 2 to 5 per cent nickel.

The deposit seems to be comparatively small, but the ore-bearing beds are so dislocated by the diorite stock and by pegmatite dikes that it is impossible to project their extensions far beyond the mine workings. The ore is probably genetically related to the pre-Cambrian diorite stock. There are several copper deposits of this general type in other parts of the Front Range but the only other known nickel-bearing deposit lies about 120 miles to the south.

*GEOLOGY, MINERALIZATION, AND PLACERS OF TARRYALL AND BEAVER CREEKS, PARK COUNTY, COLO.**

QUENTIN D. SINGEWALD.

Recent mining activity in the Alma district has stimulated interest in an area immediately to the east, where much placer gold has been mined in both Tarryall and Beaver Creeks. Reconnaissance work has been carried on southward from the Continental Divide to determine the source of the placer gold and the possibilities for lode deposits.

At the surface are Pennsylvanian and Permian sedimentary rocks, predominately clastic, intruded by early Tertiary igneous rocks. The sedimentary series, 8,000 feet thick, lacks definite "marker beds," yet these generalized units can be recognized. Generally the middle unit has thick limestone beds at the top and bottom and thinner ones between. The regional easterly dip is interrupted by two northward trending major structures and by an east-west shear belt in which is the apex of a small stock. Virtually all the known mineralized rock in the district surrounds this stock. Epidote is the most conspicuous alteration product. Magnetite, specularite, and garnet at various places attest to an initial high temperature. Later pyrite, rarely accompanied by other sulphides, associated with quartz, epidote, and other nonmetallic minerals is present in innumerable small veins and impregnated rocks that contain a little gold, but these deposits have been productive only to an insignificant degree.

Placers occur only in streams draining the mineralized area, so the gold evidently was derived from the innumerable small veins. Reasons are presented for considering the area not very favorable for bed rock prospecting, although there is some chance of finding small deposits in the limestone members of the middle stratigraphic division, below the surface along the margins of the zone of altered rock.

*VEIN SOLUTIONS AND ROCK ALTERATION IN THE BOULDER COUNTY TUNGSTEN DISTRICT OF COLORADO.**

T. S. LOVERING.

Zones characterized by an abundance of 1, montmorillonite, hydromica and sericite; 2, beidellite; 3, dickite; and 4, sericite, hydromica, orthoclase and quartz, are apparent in the alteration of oligoclase granite as a ferberite vein is approached, the minerals of the zones closer to the veins replacing those characteristic of the zones farther away. The accessory ilmenite is slightly altered to leucoxene in zone 1, slightly altered to hematite and leucoxene in zone 2, strongly altered to hematite and leucoxene in zone 3, altered to pyrite, magnetite (?), titanite and leucoxene in zone 4.

The vein filling consists of ferberite and many generations of fine-grained quartz carrying minor amounts of ankerite, alunite, clay minerals, barite, sericite, hydromica, ferberite, hematite, and pyrite. Minute crystals of alunite and hydromica are present in nearly all the vein quartz but are especially abundant in the pre-ferberite vein filling. Hematite is found in the quartz formed shortly before the ore. A little ankerite and pyrite are approximately contemporaneous with the ferberite but locally

marcasite is present. Beidellite is later but closely associated with the ferberite and is followed by quartz carrying hydromica and some orthoclase. This in turn is earlier than opal. Locally ferberite is almost completely replaced by opaline quartz and montmorillonite associated with barite.

The succession of minerals and their character indicate acid sulphate solutions passing through the vein fissures for a relatively long period and a shift toward alkaline solutions at the time the ferberite was deposited. Locally where the solutions again became sufficiently acid, the ferberite went back into solution, but in general the deposition of ferberite coincided with a shift from oxydizing to reducing solutions, and it is believed that the strong sericitization of the walls took place at this time and later.

A HIGH TEMPERATURE—INTERMEDIATE PRESSURE MOLYBDENITE DEPOSIT AT RENCONTRE EAST, NEWFOUNDLAND.[1]

D. E. WHITE AND EDWARD SAMPSON.

In a large Paleozoic granite batholith intruding a thick series of Ordovician (?) volcanics, late-phase aplite occurs mainly in an irregular zone along part of the margin. The aplite is gradational over several feet into granite and is (rarely) intrusive into granite. Both granite and aplite are in places miarolitic. Pegmatitic phases of the granite are rare. Shallow depth of intrusion is deduced from the miarolites and the predominance of aplite over pegmatite.

Molybdenite ore occurs in the aplite at or near the contact with the volcanics. Areas of mineralization appear related to gentle re-entrants of aplite in volcanics. In the ore zone quartz, muscovite, molybdenite, fluorite, and minor chlorite with magnetite have replaced aplite. Quartz and muscovite-rich rocks are distinctive. Silicification and muscovitization were probably contemporaneous, with silicification in advance of muscovitization; however, either may occur without the other. Molybdenite generally favors muscovitized rock, although in places abundant in silicified rock, and present in otherwise unaltered aplite.

Mineralizing solutions appear to have penetrated the aplite intimately without any marked structural control, giving a blotchy distribution to the alteration. Solution channels for the quartz, muscovite, and molybdenite did not always coincide. The ore mineralization of the "complex aplite" is comparable to that of complex pegmatites.

STRUCTURAL RELATIONS OF SOME GOLD DEPOSITS BETWEEN LAKE NIPIGON AND LONG LAC, ONTARIO.

E. L. BRUCE.

Gold is being mined at several places along a belt lying 50 miles north of Lake Superior, extending east from Lake Nipigon to Long Lac. The structural relations of the ore bodies at the following mines will be briefly

[1] Published with the permission of the Newfoundland Government Geologist.

discussed—Northern Empire, Leitch, Sand River, Bankfield, Little Long Lac, MacLeod-Cockshutt, and Hardrock. Most of the ore bodies are in sediments. They occur in shear zones along the axial planes of minor folds, along bedding planes, along the contacts, between dikes and sediments, and along the tips of tongues of porphyry stocks that intrude sediments. One vein occurs entirely in lavas.

In general the ore bodies are localized where there is considerable heterogeneity in the country rocks. Basic volcanics show considerable variation in the degree of schistosity in different parts of flows and veins occur in schistose zones lying between massive parts of successive flows.

NOMENCLATURE OF THE MEGASCOPIC DESCRIPTION OF ILLINOIS COALS.[1]

GILBERT H. CADY.

The British names vitrain, clarain, and durain and the more commonly used name fusain have been adopted by the Illinois State Geological Survey as an aid in the megascopic description of the material composing the coal beds of the Illinois coal basin. Expanding activities in our laboratories in matters related to and dependent upon the physical components of our coal beds have made necessary the adoption of a technique of megascopic description that can be readily understood and easily used by both the technician and the layman. This terminology of description has not been widely used in America, but its merits are such as to inspire hope for its general adoption. To the ends that standards of usage may be established as soon as possible, the present explanation of the application of the terms to Illinois coals is advanced. The explanation requires some consideration of the original definitions of the terms and of Continental usage. The Illinois State Geological Survey has endeavored to adhere closely to the denotations of the original definitions.

THE GEOLOGY AND DEVELOPMENT OF THE MILL CLOSE MINE, DERBYSHIRE, ENGLAND.

JAMES G. TRAILL.

This famous old English lead mine works a lead-zinc deposit in Carboniferous Limestone, under a shale capping. The orebodies, continuous for 15,000 feet, bear a striking resemblance to the "manto" deposits of Mexico. Ore solutions have taken the path of least resistance from source to surface and the course followed has been controlled by such factors as dip of the strata, jointing and faulting, presence of impermeable lava flows, existence of beds favorable to replacement. Ore is found underneath impermeable lavas and shales, with a vertical height of 100 feet or so, in a remarkable series of interconnecting orebodies, as veins, flats, pipes and caverns, along joints of three systems. Primary minerals are galena (with practically no silver), sphalerite (with 1 per cent cadmium), calcite, fluorite, and barite. Deep secondary mineralization may be accounted for by artesian circulation. Water flow is heavy.

[1] Presented with the consent of Dr. M. M. Leighton, Chief, Illinois State Geological Survey.

MINERAL PARAGENESIS AT LEADVILLE, COLORADO.

EDWARD P. CHAPMAN.

Various sulphides of lead, bismuth, and silver, with tellurides and native gold, accompany chalcopyrite in a sub-stage of mineralization near the close of the "Intermediate Mesothermal Period" of mineralization in the Leadville District as recognized by Loughlin and Behre. For convenience this sub-stage is called the "Bismuth Period." Minerals occurring in it are later than the customary pyrite, sphalerite, and galena, and, with the exception of gold, seem contemporaneous with each other. Gold may be in part contemporaneous but in most instances is distinctly later. Ores showing minerals of this "Bismuth Period" have been found near the centers of mineralization and deep down along the well recognized channel of mineralization, the Tucson-Maid fault. This distribution corresponds closely to the occurrence of gold values. Where minerals of this period are superimposed upon earlier ore bodies, the value has been increased by the addition of silver and in places gold; where they can be mined alone, high grade hypogene ore has resulted. This suggests deeper prospecting along known ore channels may be commercially successful.

The occurrence of arsenopyrite and pyrrhotite is recorded, and the use of chalcopyrite inclusions in sphalerite as a possible criterion for appraising the distance of the occurrence from trunk channels is commented upon.

OUTCROPS OF ORE SHOOTS.

HARRISON SCHMITT.

The study of the "outcrops" of ore shoots includes the theory on the variations in hypogene and supergene shapes and compositions and the theory of structural localization of ore shoots. In a given district, the detailed structural picture of the country rock and the characteristics of the developed ore shoots is important background.

Certain developed "outcropping" ore shoots in the Southwest and in northern Mexico are described. Special methods used for their study, besides the well known technique on textures of "limonites," including quantitative work on wall rock changes and on the distribution of the metals in the known shoots.

SIGNIFICANCE OF BORNITE–CHALCOCITE MICROTEXTURES.

G. M. SCHWARTZ.

The working out accepted interpretations of the microtextures of ores has proven to be difficult. The large number of microtextures described for such a single pair of minerals as bornite and chalcocite, serve to indicate the reason for some of the difficulty. Following is a list of bornite-chalcocite microtextures.

1. Replacement along fractures and veinlets. Mesh patterns and "ice cake" texture.
   (*a*) Bornite replaced by chalcocite.
   (*b*) Chalcocite replaced by bornite.
2. Replacement controlled by cleavage.
   (*a*) Bornite replaced along cleavage by chalcocite.
   (*b*) Chalcocite replaced along cleavage by bornite.
3. Rim Pattern. Replacement along boundaries.
4. Reticulate Texture.
5. Graphic and subgraphic textures. Pseudo-eutectic or myrmekitic texture.
6. Pseudomorph textures.
   (*a*) Bornite cleavage preserved in chalcocite.
   (*b*) Bornite pseudomorphous after chalcocite crystals.
7. Lamellar, lattice, grating, Widmannstätten, bladed intergrowths.
8. Triangular (octahedral) pseudo-eutectic or eutectoid intergrowths.
9. Spindle shaped inclusions—Ex-solution texture.
   (*a*) Bornite inclusions in chalcocite.
   (*b*) Chalcocite inclusions in bornite.
10. Mutual boundaries.
11. Concentric textures.
12. Shred-like inclusions.
13. Inclusions along zones.

The various textures are briefly described and illustrated. A review of the possible significance of each is given.

GEOLOGIC SIGNIFICANCE OF MINOR ELEMENTS IN SPHALERITE.

R. E. STOIBER.

Sphalerite from seventy-five localities has been analysed spectrographically for elements that occur in amounts of less than one per cent. These data suggest that the concentrations of the minor elements are characteristic both of the metallogenetic province and of the temperature type of the deposit in which the sphalerite is found.

There is a contrast in the kind and amount of minor elements in sphalerite from low, intermediate and high temperature deposits. The germanium and gallium concentration in sphalerite is lowest from high temperature occurrences and highest from low temperature deposits. The reverse is true of the manganese concentration. Variations in indium, tin, and cadmium are less clearly defined. The greatest concentrations of these elements are not found in sphalerite from low temperature deposits.

Variations in the composition of sphalerite from deposits of similar temperature type appear to be partly accounted for by the fact that different metallogenetic provinces are represented. Zince ores of the Mississippi Valley, barite ores of Central Kentucky, and the European zinc ores of Mississippi Valley type are all low temperature deposits, yet in the sphalerite from each province there is a restricted group of minor elements present in distinctive quantity.

RELATION OF OREBODIES TO ROCK STRUCTURE IN THE INTERSTATE MINE, WALLACE, IDAHO.

H. E. McKINSTRY AND ROBERT H. SVENDSEN.

The ore bodies occupy shear zones along which the country rock, a folded slate, has been displaced horizontally. The oreshoots are confined to places where the shear zones intersect portions of the folds in which the bedding is relatively flat. Where the beds are steep they have yielded to deformation by the shear by bending or buckling aided by slipping on the bedding planes. Where the beds are flat they have been unable to yield in this manner and have, instead, yielded by fracturing and shattering. The shatter zones so formed have offered a locus for ore deposition. Coincidentally, the shear zone varies in strike under the influence or varied attitudes of bedding and of pre-existing planes of weakness. Such irregularities have had a direct influence on the localization or ore.

GEOLOGY OF HIWASSEE DAM SITE.

BERLEN C. MONEYMAKER.

Hiwassee Dam, now under construction by the Tennessee Valley Authority, is located on Hiwassee River in southwestern North Carolina. The dam, a straight, overflow, gravity structure about 300 feet high, is founded entirely on the Great Smoky formation, which consists of metamorphic rocks derived from coarse to fine clastic sediments of pre-Cambrian (?) age.

The geology of the dam site is complex and bears upon engineering problems. The rocks are gneisses and schists that have undergone at least two periods of metamorphism and deformation. Bedding planes as shown only by differences in materials. The beds strike nearly parallel to the river (NE–SW) and dip steeply toward the left abutment (SE). Strike faults of steep southeast dips occur, but all of them are tight ancient structures. Joints are extensively developed in the upper portion of bedrock throughout the foundation and both abutments.

As bedrock was either exposed, or concealed by a thin mantle, the overburden consisted mainly of openly jointed and badly decayed rock. Excellent foundation rock was found at relatively shallow depths in both abutments but in the river section unsound rock extended to much greater depths. Weathering along sheet joints, resulting in seams of decayed rock essentially parallel to the surface topography, gave rise to the most serious defects encountered.

SOME GEOLOGICAL FEATURES OF KOLAR, PORCUPINE AND KIRKLAND LAKE.

E. Y. DOUGHERTY.

Kolar in Mysore State, South India, and Porcupine and Kirkland Lake in Ontario are three of the world's prolific lode-gold producing districts. In each of the three districts the ore has shown notable depth persistence

and promises to continue still deeper. Large profits have been won from its exploitation.

The geology and ore deposits of the three districts have many analogous features and instructive dissimilarities as well. Some of these are summarized. Practical considerations arising from the geological conditions are discussed. The lodes of the three districts are in pre-Cambrian rocks and the ore itself is of pre-Cambrian age. The areal and space relations of the deposits to granitoid batholiths vary, but have analogies. The major ore zones of all three districts are on the limbs of regional synclines. It is concluded that the localization of the major lode fissuring of all three districts depended fundamentally on shearing movements, and that recurrent or continuous application of the compressive forces responsible for regional folding are probable causes of these shearing movements. Complexity, strength and persistence of major fissured zones are the physical geological reasons for the notable productivity and persistence of the major ore zones of the three districts. The broader time relations of ore deposition, hypabyssal intrusion and deformations are analogous in the three districts, with some interesting differences. Space relations of ore to intrusives vary in each district and among the three districts. Rock structure has influenced the emplacement of hypabyssal intrusives and has controlled everywhere the disposition of lode quartz. Genetic relation of the lodes of the three districts to spacially closed associated salic intrusives is probable.

Collectively the lodes of the three districts appear to span the hypothermal to mesothermal groups. Origin of the deposits from silicious magmatic differentiates is particularly convincing at Kolar and reasonable at Porcupine and Kirkland Lake. There are mineralogical links between the deposits of the three districts that suggest a fundamentally similar origin.

Practical considerations based on the summarized data are discussed in the latter part of the article.

THE GEOLOGY OF THE CANADIAN MALARTIC GOLD MINE.

D. R. DERRY.

The geology of the Canadian Malartic gold mine, Quebec, shows the following features of especial interest: (1) An interesting combination of structural features affecting the position and shape of the ore bodies, (2) the presence within the area of the mine of two entirely different types of auriferous ore bodies, (3) the fact that the second of these consists of gold in material akin to pegmatite; this is discussed in detail.

The mine occurs in graywacke sediments intruded by bodies of porphyry of pre-Cambrian age. The graywacke has been drag-folded by stresses other than those which caused the main syncline on which they occur, and which has influenced the shape of the porphyry bodies; the subsequently sheared and brecciated zones show a close association with both. The bulk of the ore consists of altered and mineralized graywacke along zones of brecciation. Evidence shows that the gold mineralization was somewhat later, and followed more limited zones, than the solutions that caused the silico-carbonatization and pyritization of the brecciated graywacke.

The "pegmatitic" ore lies only within the unsilicified portion of the main porphyry body. It occurs in veins and in three sets of fracture zones. These fractures appear to be associated with slip-planes following wide chloritic seams that may be either chloritized graywacke inclusions or basic dikes. The gangue of these veins consists mainly of quartz, albite and some pyrite, but also includes calcite, tourmaline, micas, scheelite, rutile and other rarer minerals. Gold values, although erratic, are higher than in the typical graywacke ore. The question of whether the gold is an original constituent of the pegmatitic assemblage or whether it was added after later re-fracturing is discussed. Evidence seems to favour the former alternative. It is suggested that the gold in the main ore zones in the graywacke may have been added to the altered and pyritized breccia at about the same time as the pegmatitic veins were being formed within the porphyry.

SCIENTIFIC NOTES AND NEWS

GEOFFREY GILBERT has returned from Salmijarvi, Finland, to Toronto.

ERNEST R. LILLEY of New York University has been made Director of the Geological Museum at University Heights.

E. N. PENNEBAKER has completed geological investigations at Matahambre, Cuba, and British Columbia and has returned to Kimberley, Mo.

WALDEMAR T. SCHALLER was awarded the Roebling Medal by the Mineralogical Society of America at the Christmas Meeting in New York.

E. C. MOORE, Vice-President Elect of the Society of Economic Geologists, succeeds A. C. Veatch, deceased President Elect, as President of the Society for the ensuing year.

GEORGE GARREY was married to Mrs. Bradish Morse on December 10th in New York. They are living at 1555 Sherman St., Denver, Colo.

L. C. GRATON, who is on leave from Harvard this year, was in Australia during the Christmas period.

A. C. VEATCH died in New York on December 24.

JEAN VERHOOGEN has returned from the Belgian Congo to 22 rue Joseph II, Brussels, Belgium.

CHARLES W. WRIGHT will shortly return from England to the United States and will continue his minerals investigation work in South America.

FREDERICK G. CLAPP has returned from the East and is continuing his consulting practice at 50 Church St., New York.

THE SOCIETY OF ECONOMIC GEOLOGISTS will hold an informal dinner in New York in March for the presentation to Reno H. Sales of the Penrose Gold Medal of the Society. Mr. Sales left at the beginning of January for a trip to Chile and will return sometime in March.

THE MINING AND METALLURGICAL SOCIETY OF AMERICA at its December meeting held a symposium on strategic minerals, which culminated in a resolution to the Administration and Congress recommending accumulation of emergency stocks of specific strategic minerals for war preparedness.

The following lectured recently before the department of Geology and Geography, Northwestern Univ.: W. H. VOSKUIL, Mineral Economist, Ill. Geol. Survey, on "Economics of Mineral Production"; C. P. Ross and D. F. HEWETT, of the U. S. Geol. Survey, on "Cinnabar Deposits of California" and "Mining Geology in the Western United States"; B. B. COX, Vacuum Oil Co. on "Modern Petroleum Development"; J. H. MAXSON, Cal. Inst. of Technology, on "Geologic Studies in the Grand Canyon of the Colorado"; H. T. STEARNS, Hawaii on "Hawaiian Volcanoes"; TAKEO WATANABE, Univ. of Sapporo, Japan on "Japanese Geological Institutes"; and G. W. WHITE, Univ. of New Hampshire on "Novya Zemlya."